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WILLIAMS AIR FORCE BASE AIR QUALITY MONITORING STUDY.(U)

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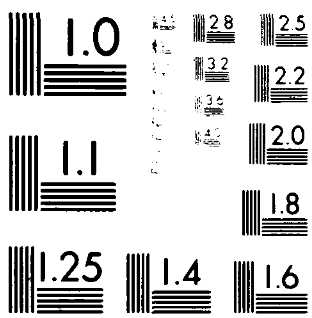

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Williams Air Force Base Air Quality Monitoring

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WILLIAMS AIR FORCE BASE AIR QUALITY MONITORING STUDY

by

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FOREWORD

Protection of the environment requires effective regulatory actions based on sound technical and scientific data. The data must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of exposure to specific pollutants in the environment requires a total systems approach that transcends the media of air, water, and land. The Environmental Monitoring Systems Laboratory at Las Vegas contributes to the formation and enhancement of a sound monitoring-data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment

- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report presents an evaluation of the impact of aircraft operations on air quality at Williams Air Force Base near Phoenix, Arizona. The data reported here will serve as input for defining the accuracy limits of the Air Quality Assessment Model. This program was funded by the Department of the Air Force, Department of the Navy and the U.S. Environmental Protection Agency under an interagency agreement.

Director
Environmental Monitoring Systems Laboratory
Las Vegas, Nevada

SUMMARY

This report describes measurements made and data obtained during 13 months of continuous air quality monitoring at Williams Air Force Base near Phoenix, Arizona, during the period from June 1976 through June 1977. Air quality parameters monitored from a network of five ground trailer stations included carbon monoxide (CO), methane (CH_4), total hydrocarbons (THC) measured as methane, nitric oxide (NO), total nitrogen oxides (NO_x), and coefficient of light scattering (b_{scat}). Meteorological parameters monitored included wind speed and direction (WS and WDO, solar insolation, and (for three months only) orthogonal wind components (u, v, and w) and mixing depth.

Data collection and analysis were oriented toward three primary objectives:

1. The production of an air quality and meteorology data base for use in defining accuracy limits for the Air Quality Assessment Model (AQAM) formulation
2. The determination of the impact (if any) on Williams Air Force Base (WAFB) air quality at ground level resulting from aircraft operations
3. The evaluation of results obtained from related special studies designed to characterize horizontal and vertical dispersion of WAFB emissions

Data recovery was determined to be approximately 70 percent for the 13-month monitoring period. Based upon analysis of this data set, results indicate that no significant air quality impact resulting from WAFB aircraft operations was measured at any of the five ground stations. With the exception of concentrations for CO and nonmethane hydrocarbons (NMHC, or hydrocarbons corrected for methane), the data indicate only slight differences between local airbase and background air quality concentrations. These differences lie within the determined range of experimental measurement error. Meteorological data indicate persistent diurnal windflow patterns, and correlation of pollutant concentrations with windflow reveals that the main sources of pollutants are indigenous to the airbase, thereby making feasible the comparison between measured data and the AQAM predictions.

Results derived from related special studies conducted at WAFB suggest that two or three categories of mixing height should be chosen in order to evaluate AQAM performance, that jet plume rise and downwind horizontal dispersion measurements are necessary in order to evaluate off-base air quality impact, and that remote measurement techniques (although not completely developed or standardized) may prove useful in the monitoring of airbase air quality and dispersion of aircraft emissions.

Previous airport studies to evaluate models for prediction of air quality impact suffered from the fact that nearby urban sources of pollutants masked the airport emissions. Williams Air Force Base, Arizona, about 40 miles southeast of Phoenix, was selected as an isolated, high-volume air traffic facility to study airbase and aircraft emissions activity. Selection of Williams enabled the monitoring of airbase emissions in an ambient environment relatively free from nearby sources of pollutants that would interfere with measurements made in the vicinity of airbase emissions.

Project planning was done by the U.S. Environmental Protection Agency, U.S. Air Force (USAF), U.S. Navy and Argonne National Laboratories (ANL). Planning included the siting and determination of numbers of stations to be used, pollutant-sensor selection, and definition of aircraft operations to be studied. Station siting also involved an evaluation of historical meteorological data and the physical layout of the base. Monitoring stations were located adjacent to aircraft operations to monitor queueing, departure, and arrival of aircraft as well as related base sources of emissions. Two stations were located in areas on the base that were expected to be least impacted by local emissions, as anticipated during the study design. The resulting five-station monitoring network was linked to a central recording system for automatic data acquisition at one-minute intervals.

The instrumentation for continuous monitoring of air quality used in this study was representative of the state of the art available in 1975 in terms of second-generation instrument development and techniques for calibration and operation.

The following instruments were selected based upon their availability and on previous Environmental Monitoring Systems Laboratory (EMSL) experience:

- Gas chromatograph with continuous flame ionization detector for THC, CH_4, and CO in the parts-per-billion (ppb) to parts-per-million (ppm) concentration ranges, a wide linear range, and a self-calibration feature

- Dual-reaction-chamber chemiluminescent analyzer for NO and NO_x in the ppb concentration range

- A nephelometer for light scattering in the visible wavelength (measured scattering coefficient is then related to the visible range in the atmosphere)

- WS and WD propeller vane sensors located approximately 8 (meters) above ground level (AGL)

The monitoring systems network was subjected to a daily routine of inspections, calibration checks, and preventive maintenance. Additional meteorological sensors were utilized during various phases of the study to collect specific information relating to atmospheric stability and dispersion. These sensors included a pyranometer, an acoustic sounder, orthogonal wind component sensors, temperature differential probes, and boundary layer profile sensors.

Automatic data acquisition included the recording of continuous measurements for oxides of nitrogen (NO_x), methane (CH_4), total hydrocarbons (THC) measured as methane, carbon monoxide (CO), wind speed and direction, and nephelometer scattering coefficient. Data were digitized, recorded, and stored on magnetic tape. Four levels of data processing were performed at both Williams AFB and EMSL in Las Vegas, Nevada. One-minute data were converted to hourly averages and provided on tape to ANL to perform the accuracy definition of AQAM under contract to the U.S. Air Force. Air quality averages were compiled as tabular summaries and monthly plots of concentration versus time.

Data processing activities for the WAFB project included the following activities:

- Handling one-minute data tapes acquired from the air monitoring network and verifying the contents of these tapes

- Calibrating the one-minute voltage tapes and converting the voltages to engineering units

- Averaging the one-minute data to produce hourly averages and calculating the root mean square average, the standard deviation, and the maximum and minimum for each hour

- Coding, Williams Air Force Base Aerometric Network (WABAN) meteorological data onto computer forms and tape cartridges and merging these data into a data file of consistent format for each month that air quality data were collected

- Presenting data in the form of tabular listings of hourly data, frequencies and cumulative frequencies of NO, CO, NMHC, and b_{scat} (nephelometer), cumulative frequency distribution plots of these four parameters, time plots of the hourly averages, time plots of minute values for four Julian days, and microfiche of the tabular listings

- Compressing 395 one-minute data tapes onto a 20-reel set for use by ANL in AQAM accuracy definition analysis

Digital voltage data from each of the five monitoring stations were recorded at one-minute intervals on magnetic tape in the central data acquisition facility (Building 16) at WAFB. Procedures were developed to convert the one-minute air quality data to hourly averages. The hourly-averaged data are presented in tabular summaries and monthly plots of concentration versus time. The data set includes all continuous air quality and meteorology data taken from the air monitoring network over a 13-month period. Processing required several levels of interactive editing with the use of control charts of zero, span, and calibration information to support data correction and adjustment. Checks for internal consistency were uniformly applied during data processing, and transmittal errors and rejected data were identified. Data were accepted or rejected through editing, verification, and screening based on a predetermined set of criteria. The

goal in processing was to assure that corrections were made for causes documented in operations logbooks for each monitoring station of the network.

Meteorology data collected as hourly observations on WABAN forms were coded by the USAF and provided on one magnetic tape. This tape also included the acoustic sounder mixing depth information. Additional meteorology data collected at monitoring station 4 from April to June 1977 are available on the one-minute magnetic tapes collected in the central data acquisition facility.

Although the related special studies conducted at Williams Air Force Base have provided insight into the general aspects of pollutant dispersion at WAFB, current analyses of the results of these studies have not led to specific conclusions with respect to WAFB emissions impact on base air quality. Integrated long-path monitoring for CO and NO_x shows promise of providing viable techniques to describe dispersion at airbases. The amount of aircraft emissions, combined with some long-path CO measurements taken adjacent to taxiways, suggest that jet exhaust plumes rise quickly in the vicinity of emissions. Micrometeorological studies to measure parameters important for describing mixing depth and vertical and horizontal dispersion suggest that significant improvement can be made to site-specific models used to assess emissions impact at airbases. A single jet exhaust study using a helicopter platform showed jet plumes at significant vertical height (47 m) relatively close (200 m) to the point of emission.

Conclusions drawn from these studies are relevant as far as the assessment of air quality at the five monitoring stations. Commercial monitoring instrumentation has limits of detection that restrict its usefulness for the collection of model input data at ground level in the vicinity of jet exhaust emissions. An additional limitation at WAFB was caused by the immediate vertical rise of exhaust emissions, placing pollutants at altitudes that are not sampled by ground-based analyzers.

Twelve months of data were selected and averaged to provide an annual basis for assessing air quality at the five monitoring sites. Ambient concentrations of NO_x, NMHC (hydrocarbon corrected for methane), and CO were measured at and near the limits of detection for the continuous analyzers. However, sufficient calibration and daily check data were maintained to allow a determination of measurement precision and accuracy limits for the data set collected.

Valid data were recovered for 70 percent of the 13-month monitoring period, and the data base is representative of ambient air quality at WAFB in the vicinity of the ground monitoring sites. On an annual average basis, there is persistent evidence of emission sources, particularly in the case of CO concentrations. The data indicate a measurable effect on air quality at ground stations 2, 3, 4 and 5 as a result of aircraft operations. In addition, the effect on air quality as measured at Station 4 is separate and distinct from that at stations 2, 3 and 5 resulting from nonaircraft-related base operations. However, neither of these measured effects is significant in the context of the determined range of experimental measurement error. Results of the related special studies also support this conclusion, although the time period of investigation for these studies was considerably shorter.

In relation to the National Ambient Air Quality Standards (NAAQS), ambient concentrations measured at WAFB did not at any time exceed the NAAQS for CO and NO_2 (determined by the fact that NO_x concentrations never exceeded the NAAQS for NO_2). Concentrations of NMHC exceeded the recommended 6:00 a.m. to 9:00 a.m. guideline only at times other than 6:00 a.m. to 9:00 a.m.

The Williams AFB experimental study demonstrated conclusively that aircraft and airbase emissions did not impact air quality significantly in the vicinity of emissions that contribute the major pollutants (CO and HC). Results of the related special studies and the continuous monitoring suggest that dispersion of hot exhaust from aircraft occurs very quickly at WAFB, and the typical WAFB meteorological condition affords a low potential for exceeding the NAAQS.

The methods for acquiring data to define the accuracy of a model need careful study in subsequent airport programs designed to develop models useful for predicting impact on ambient air quality. The development of monitoring systems to measure plumes above ground level was shown to be feasible, based on limited studies at Williams AFB. Therefore, a carefully conceived monitoring system consisting of appropriate emphasis on local meteorology, elevated sampling, and limited ground monitoring is recommended for subsequent studies of air pollution emissions at airbases.

Monitoring over long-path lines at ground level may also permit the collection of data more consistent with model results. Monitoring objectives to collect data in relation to NAAQS compliance should be considered as separate and distinct from those for acquisition of model input data since the monitoring technology required for each is different.

One significant result obtained from the WAFB study was the realization that air quality impact cannot be effectively determined in areas where emissions take place at elevated temperatures (aircraft exhaust) through the use of ground sensors located in the vicinity of the emissions. Sensors must be placed in locations where emissions are predicted to have maximum impact as determined by study of historical meteorology and by intensive above-ground measurements conducted to characterize pollutant transport away from the emission sources (horizontally and vertically).

Statistical meteorological studies should be conducted for the Naval Air Station (NAS) to provide specific information for site selection and determination of the number of sites needed for both model data base input and impact assessment. Station siting should also be dependent upon the number and location of significant emission sources.

Micrometeorological data should be acquired in order to determine horizontal and vertical dispersion parameters together with atmospheric stability classifications. These data can be obtained by use of tethered balloon platforms and boundary layer profile sensors. Above-ground air quality measurements should be conducted from tower or airborne platforms to quantify the vertical transport of emissions away from the study area. In addition, horizontal pollutant dispersion should be measured during representative meteorological conditions by making intensive measurements over

short time periods from a network of portable ground sensors. The latter is particularly appropriate in terms of measuring particulate transport.

Emissions and their dispersion need not be monitored continuously for extended periods of time if data are obtained during each representative meteorological condition, unless the data collected prove to be inconclusive. Ground sampling data must be acquired in the vicinity of known emissions (such as hot refueling) and in locations some distance from known sources (for example, off base or near airbase boundary) to determine changes in air quality and to qualitatively measure pollutant transport.

Short-term intensive monitoring is also recommended in order to determine the relationship between dispersion data and data from the fixed ground sites. Airborne and balloon-borne sensors are effective in this approach, and these data should be incorporated with local micrometeorology to make a determination of local source contributions.

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Appendices*

* The Appendixes are available from National Technical Information Center, Springfield, VA 22161

FIGURES

TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

A	--	ampere
AF	--	Air Force
AFB	--	Air Force base
AFCEC	--	Air Force Civil Engineering Center, Kirkland AFB, New Mexico
AGL	--	above ground level
ANL	--	Argonne National Laboratory
AQAM	--	Air Quality Assessment Model
AVAP	--	Airport Vicinity Air Pollution Model
BDCS	--	Bendix Dynamic Calibration System
Btu	--	British thermal unit(s)
BPI	--	bits per inch
CDC	--	Control Data Corporation
CEEDO	--	AF Civil and Environmental Engineering Office, Tyndall AFB, Florida
COSPEC	--	Barringer correlation spectrometer
DEC	--	Washington National Airport
EMI	--	Environmental Measurements, Inc.
EMSL-LV	--	Environmental Monitoring Systems Laboratory, Las Vegas, Nevada
EPA	--	U.S. Environmental Protection Agency
ERSL	--	Environmental Research Support Laboratory, NSI, Research Triangle Park, North Carolina
FAA	--	Federal Aviation Administration
GFC	--	gas-filtered correlation spectrometer
HP	--	Hewlett-Packard Corporation
Hz	--	hertz
IITRI	--	Illinois Institute of Technology Research Institute
IRG	--	interrecord gap
kw	--	kilowatt
ML	--	Monitor Labs Corporation
MOA	--	Monitoring Operations Division, Air Quality Branch (EPA/EMSL-LV)
MRI	--	Meteorology Research, Inc.
mV	--	millivolt
NAAQS	--	National Ambient Air Quality Standard
NBS	--	National Bureau of Standards
NMHC	--	nonmethane hydrocarbon
NOAA	--	National Oceanic and Atmospheric Administration
NREC	--	Northern Research and Engineering Corporation
NSI	--	Northrop Services, Inc.
pibal	--	pilot balloon
ppb	--	parts per billion
ppm	--	parts per million
ppmM	--	parts per million - meters

ROSE	--	remote optical sensing of emissions system
rpm	--	revolutions per minute
SLDVS	--	scanning laser Doppler velocimeter system
THC	--	total hydrocarbbons
TS	--	total sulfur
TSP	--	total suspended particulates
USAF	--	United States Air Force
UTM	--	universal transverse mercator coordinates
V	--	volt or voltage
WABAN	--	Williams Air Force Base Aerometric Network
WAFB	--	Williams Air Force Base, Arizona
WD	--	wind direction
WS	--	wind speed

SYMBOLS

SO_2	--	sulfur dioxide
NO_2	--	nitrogen dioxide
H_2	--	hydrogen
N_2	--	nitrogen
CH_4	--	methane
CO	--	carbon monoxide
NO	--	nitric oxide
NO_x	--	oxides of nitrogen
O_3	--	ozone
σ	--	sigma
ϕ	--	theta
β	--	beta
$\Delta T/\Delta Z$	--	changes in temperature with changes in height

SECTION 1

INTRODUCTION

The measurement and data acquisition techniques presented in this report describe work performed under contract to the U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada (EPA/EMSL-LV). During monitoring operations conducted from five ground stations at Williams Air Force Base (WAFB) near Phoenix, Arizona, air quality data were collected for a 13-month period (June 1976 through June 1977). Data from this experimental study are presented together with a preliminary interpretation of the WAFB impact on local air quality. These data will also be used by the U.S. Air Force (USAF) to define the accuracy limits of the Air Quality Assessment Model (AQAM) under contract to Argonne National Laboratories (ANL).

1.1 BACKGROUND

The current method of predicting the air quality impact resulting from airport operations (both in their present and future configurations) uses a properly validated air quality computer model. Few air quality models have been developed specifically to calculate airport air quality impact [1-4] because of the extremely detailed emissions input required. The function of any such model is to account correctly for pollutant emissions into the atmosphere and to describe and predict their subsequent dispersion. The Gaussian dispersion formulation is widely used in airport models because it is appropriate for the scale of distances (0-5 kilometers (km)) and short pollutant travel times (0-3 hours (h)) associated with airport emissions. Recent studies [5-9] have indicated that any air quality impact predicted by these airport models will occur on a local scale (5 km radius or less).

Two Government-sponsored, steady-state Gaussian plume dispersion models have been developed. The first model was developed under EPA contract by Northern Research and Engineering Corporation (NREC) [1] and was later modified by Geomet, Inc. [3], also under EPA contract, to improve its air quality predictive capability. It is currently referred to as either the "modified NREC model" or the "Geomet model." An attempt was made to compare results of the Geomet model with data collected at Washington National Airport (DCA) during the six-month period from October 1972 through April 1973. Accuracy comparison was incomplete, however, because of the continued presence of higher pollution levels from sources other than DCA aircraft (mostly vehicular traffic associated with surrounding roads and highways), which masked pollutant concentration variations resulting from airport sources.

The second Government-sponsored airport model was developed by ANL under contract to the USAF and the Federal Aviation Administration (FAA). This effort produced two models. The first version, the Airport Vicinity Air Pollution (AVAP) model [2], has a civilian aircraft and activity emissions input routine. Limited evaluation has been attempted on AVAP; however, no real conclusions could be drawn because of the limited amount of data available. The second, AQAM [4], has a USAF emissions inventory refinement that includes all military-type aircraft and base activities. The Gaussian air pollution dispersion algorithm used is similar in both AVAP and AQAM. The AQAM model has the capability of predicting annual concentrations, in addition to short-term air quality calculations.

A study prepared for the FAA, "A Survey of Computer Models for Predicting Air Pollution from Airports" [8], concluded that no evaluation of an airport air pollution model had been performed to date. Previous attempts to collect an adequate data base [1-3 and 8] were conducted at high traffic-volume civilian airports located in areas of high background air pollution that masked the effect of airport emissions.

Haber [8] also noted that "a controlled evaluation of the basic transport and diffusion equations" should be conducted. A controlled evaluation is particularly needed to verify current airport models that represent aircraft emissions on runways as continuous line or point sources of pollution. These formulations are based on dispersion data generated from experiments with elevated point sources of emissions. Such line-source formulations should be studied experimentally before the models receive widespread application in environmental impact assessment.

Haber's most important recommendation was that an accuracy definition program should be conducted under controlled experimental conditions. Because a controlled experiment would be nearly impossible at a civilian airport, Haber suggested that the next best experimental site would be a relatively remote, high traffic-volume, military airfield where accurate statistics would be available for aircraft type, mix, and activity schedules from which emissions input data are calculated. Requirements for accuracy definition are shown in Figure 1. Note that meteorological data are required both for comparison and model calculation.

Gaussian air quality models require model inputs for estimation of the stability of the atmosphere throughout the mixed layer, where most pollution is dispersed from moving and fixed sources. These inputs consist of meteorological measurements of vertical temperature and mean wind profiles, and vertical and horizontal wind variability with time. Air quality measurement can be applied in this way to characterize concentration profiles in three dimensions for comparison to model calculations. Remote sensing methods also provide data that may show elevated concentrations above ground, and integrated paths of concentration horizontal to the ground, for the purpose of comparing predicted concentrations to actual measurements.

Model accuracy definition requires that daily, monthly, and seasonal distributions of air quality and meteorological data be collected to evaluate the AQAM. Frequency distributions of one-hour averages of air quality

parameters are used to compare AQAM calculations to measured frequency distributions (see Figure 1).

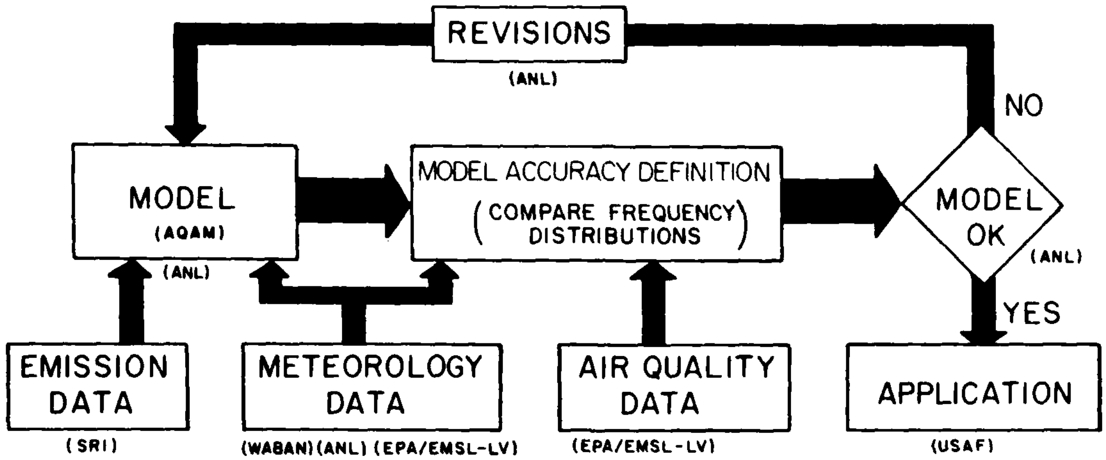

Figure 1. USAF/EPA program activities.

In summary, the Air Force AQAM accuracy limits may be defined by conducting the following activities:

- Selecting a suitable airbase, free from interfering urban pollution.
- Collecting an air quality and meteorology data base with a suitable number of ground-level sites for the assessment of model accuracy in an area of airbase emissions impact.
- Comparing frequency distributions for model-calculated pollutant concentrations to those for actual ground measurement data.

Williams Air Force Base, southeast of Phoenix, Arizona, and east of the town of Chandler, Arizona (Figure 2), was selected as a high-volume air traffic facility for a study of the impact on ambient air quality resulting from aircraft emissions and other indirect sources of pollutants on the base. Statistics were available for aircraft type, mix, and activity schedules at WAFB. WAFB offered the following advantages for monitoring and model evaluation: a large volume of aircraft traffic resulting in large estimated emissions of carbon monoxide (CO) and total hydrocarbons (THC), and relatively few local pollutant sources (resulting in low background levels), so that greater resolution of the impact of air base operations could be determined for model evaluation [10]. The emissions to be monitored for impact assessment would be CO, THC, methane (CH_4), and nitrogen oxides (NO_x) from locations in the vicinity of WAFB activities over a statistically acceptable period of time in order to obtain representative meteorological conditions.

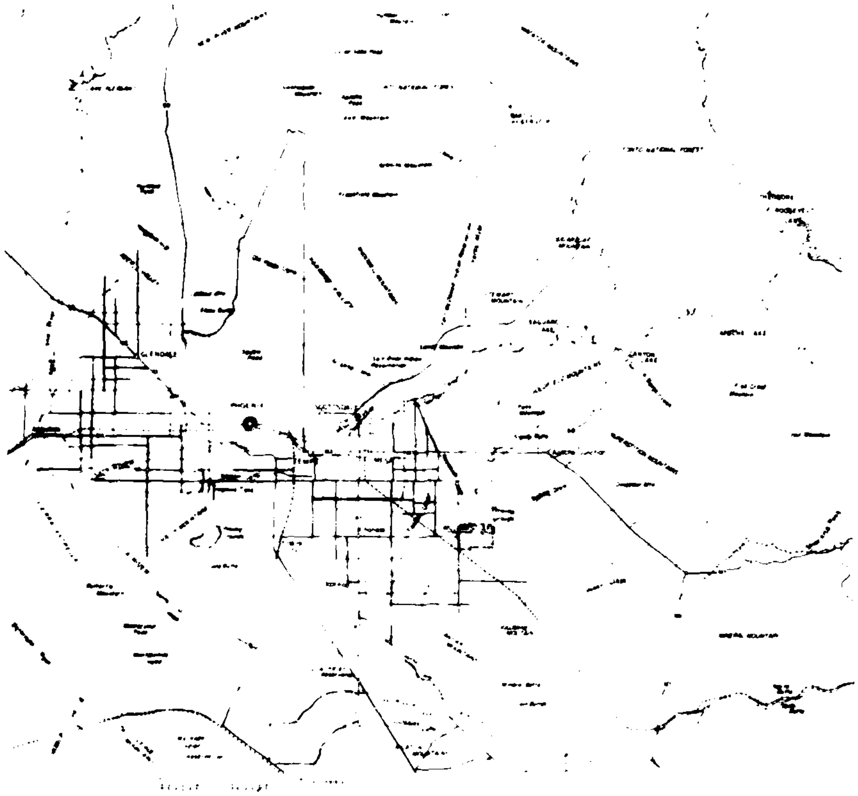

Figure 2. Map of Arizona showing WAFB.

1.2 OBJECTIVES OF THE STUDY

The USAF, the U.S. Navy, and the EPA share a common interest in determining the impact of airport activities on local air quality and in evaluating the AQAM model. They formed an interagency agreement (IAG-R5-0788) in May 1975 with the following objectives:

- To collect a data base of airport-related air quality measurements to evaluate the Air Force AQAM model.
- To determine the impact (if any) of airport-related activity on local (5-km radius) air quality.
- To conduct a series of special studies to provide information on horizontal and vertical dispersion to supplement any model revision by ANL.

The WAFB study addressed the first two objectives of the agreement by collecting data at one-minute intervals from five fixed monitoring sites at WAFB, converting the data to hourly averages and providing these hourly averages to ANL. AQAM model accuracy is to be defined by using it to

calculate one-hour average pollutant concentrations and then comparing them to frequency distributions for data collected by the WAFB air monitoring network from June 1976 through June 1977. Since meteorological and emissions data (as well as air quality data) are needed in the Gaussian formulation of the AQAM to calculate the one-hour frequency distributions (see Figure 1), daily meteorological observations from the Williams Air Force Base Aerometric Network (WABAN) were obtained during the monitoring period. Certain meteorological data were also acquired at the fixed-site ground monitoring locations.

An April 1975 feasibility study, performed at WAFB by the USAF, EPA, and ANL, was used to determine the number of monitoring stations necessary for the air monitoring network, the rationale for their location, and the suitability of measurement techniques being applied in the experimental study.

Past airport monitoring studies have not measured concentrations significantly above background levels [2, 8 and 9], possibly because the plume rise is significant as hot buoyant gases exit the aircraft engines. Meteorological conditions and runway surface temperature may also have a significant effect on plume rise. Airport models do not normally evaluate these features or incorporate terms for landing and takeoff cycles. Any evaluation of an air quality model such as AQAM will require supporting measurement data in order to define plume rise and meteorological parameters not measured by the fixed ground monitoring network. Therefore, the third objective of the interagency agreement required that additional studies be conducted at WAFB. Vertical and horizontal dispersion at WAFB were investigated during a portion of the EPA study period in order to augment the fixed-point ground-level data.

Another special study related to this project generated data to explore plume trajectories from the various indirect sources created by queuing and idling aircraft [11]. Ground-based and airborne moving sampling platforms were also used at WAFB to provide air pollution mapping. Correlation spectrometer measurements to provide insight into plume trajectory, plume rise, and points of maximum downwind concentrations were also made early in the study to satisfy the monitoring requirements imposed by objective 3. Summaries of these special studies are included in this report, and full reports are available under separate cover as indicated.

1.3 GEOGRAPHY AND CLIMATOLOGY OF THE PHOENIX AREA

Williams Air Force Base is located at latitude 33°18' N and longitude 111°40' W, approximately 40 km southeast of Phoenix, Arizona, at 422 meters (m) above sea level. This location is on the northeastern edge of a large semiarid desert valley that extends westward to the California Coastal Mountains and southward to the Gulf of California. For 16 km in every direction from the base, the land is almost flat. The nearest mountains of significance are the SanTans, 16 km to the south, and the Superstitions, 24 km to the northeast (Figure 2). Westward from the base, the valley floor is broken irregularly by small mountains and short mountain ranges. The nearest of these mountain ranges is the Sierra Estrella Mountains, which rise sharply

to more than 1,370 m above mean sea level. From the northwest clockwise through the southeast, the terrain is mountainous with many peaks above 2,000 m. Except for irrigation canals, there are no significant water features, and local air is characteristically dry.

The land to the east of the base is typical desert, covered with growths of sagebrush, cactus, and mesquite. From the southeast clockwise through the north, the land is irrigated, producing (in season) cotton, alfalfa, melons, citrus, and many vegetables. Citrus fruit groves are numerous. The Phoenix-Tempe-Mesa metropolitan area is expanding to the southeast toward WAFB, gradually reducing the quantity of cultivated land. The majority of the base is built on a rock and sand foundation with few trees and many lawns. The airfield complex is covered by either concrete, asphalt, bituminous matting, or gravel.

Windflows influenced the siting and planning of the air monitoring network. A climatological wind rose derived from WAFB weather records for the period from March 1942 to July 1967 (Figure 3) shows that the predominant wind direction (WD) is from the east through the southeast [12]. A secondary direction is from the west through the northwest. The normal diurnal pattern is for the winds to veer through 360 degrees daily. This directional pattern

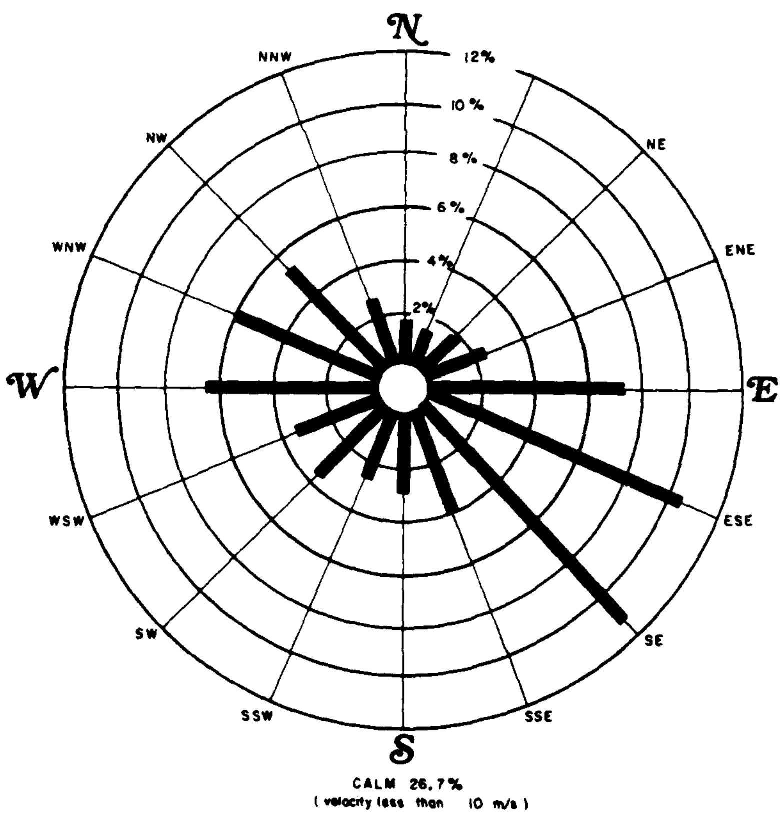

Figure 3. WAFB wind rose for March 1942-July 1967.

of surface winds persists throughout the year. At night, the low-level air cools as the result of radiative heat loss and tends to sink. This dense air flows down the mountains and into the valleys, causing drainage winds. At WAFB, flow is southeasterly from higher ground down towards the Salt River and Phoenix. Typically, by late morning the radiation inversion has dissipated and the mixed layer increases in depth. The low-level air, now less dense, flows up the valley floor surfaces and can be forced up over the mountains. This condition lasts well into the evening.

There are no dominant seasonal wind regimes comparable in magnitude to the diurnal changes. The greatest frequency of winds over 5 meters per second (m/s) occurs from April to July, and winds with speeds over 10 m/s are most commonly associated with nearby thunderstorm or frontal activity.

SECTION 2

CONTINUOUS AIR QUALITY MONITORING NETWORK

The WAFB monitoring network consisted of a central data acquisition facility (located in Building 16) and five trailers utilized as fixed-site monitoring stations (Figure 4). The central facility contained space for recordkeeping, instrument repair and maintenance, and electronic data processing. The monitoring network was composed of two subsystems--measurement sensors and data acquisition. Data acquisition included the measurements collected by continuous air quality and meteorology monitoring instruments. These measurements were recorded as digitized data on magnetic tape. Data processing was performed using equipment at WAFB, EMSL-LV, and Northrop Services, Inc., Las Vegas, Nevada (NSI).

2.1 DESIGN AND PLANNING

Planning the study design to satisfy the technical requirements of the WAFB 1975 project objectives began with identifying both the constituents to be monitored to characterize dispersion of aircraft emissions and the best monitoring technology available at that time. Continuous air monitoring instrument development had progressed to the second-generation status. Data handling from analog to digital signal processing was well defined. For the purposes of this study, CO, THC, CH_4, NO, NO_x, and nonmethane hydrocarbons (THC corrected for methane) were selected as the pollutants to be monitored in order to characterize emissions of both aircraft- and airbase-related activity.

Given the status of 1975 technology for monitoring CO, NO/NO_x, and THC, it was clear to EMSL-LV that the WAFB project objectives indicated the following technical requirements:

- Assessment of impact would require actual frequency distributions of emissions from aircraft and indirect sources around WAFB.
- Because available dispersion models yield one-hour average concentrations, the WAFB pollutant measurements would be prepared as frequency distributions of one-hour averages over a sufficient period of time to include representative meteorological conditions.
- The impact of emissions could be better determined if frequency distributions observed in areas believed to represent background levels (i.e., pollutant concentrations relatively unaffected by aircraft emissions) were compared with frequency distributions in areas known to be subjected to emissions impact.

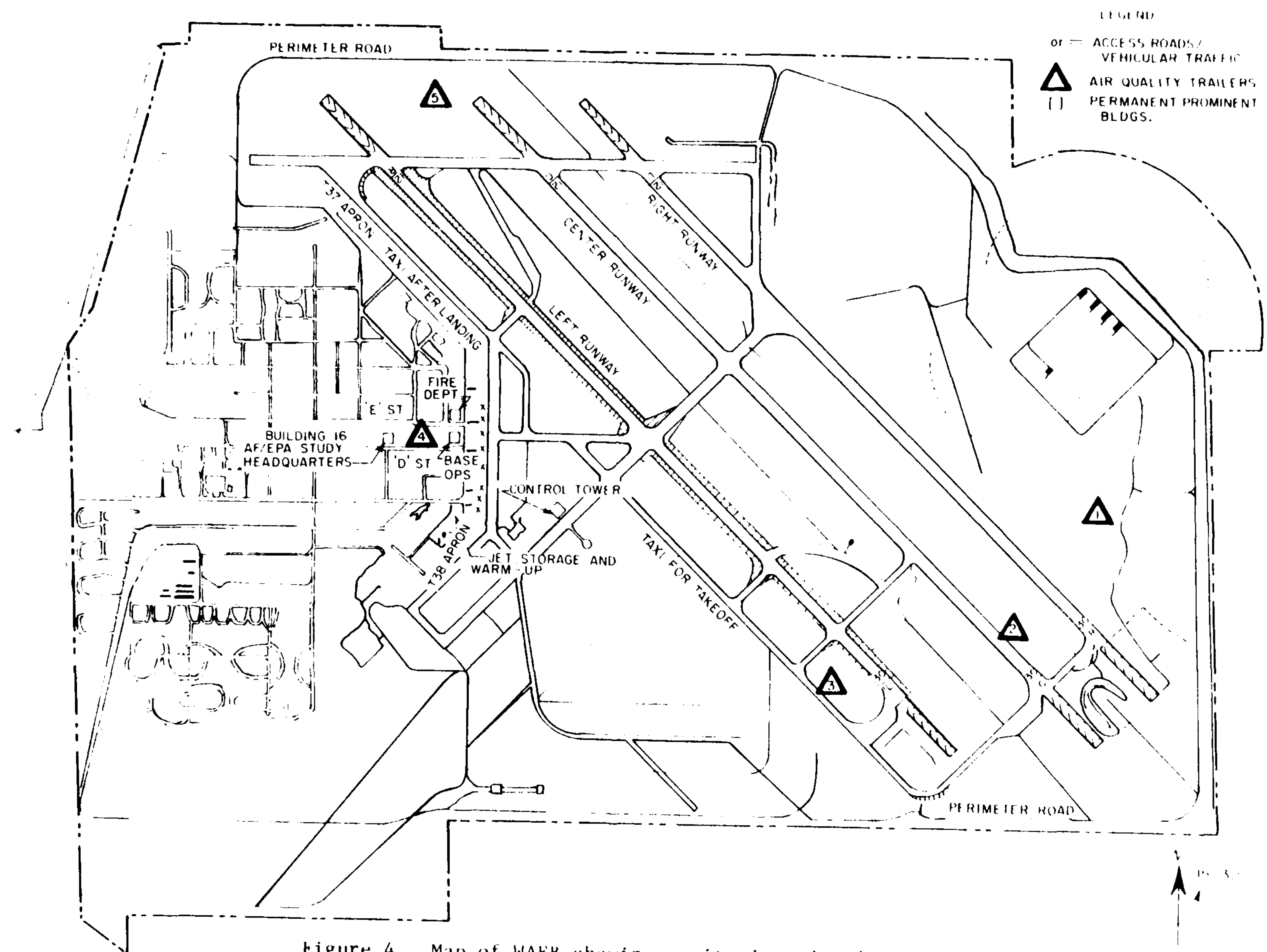

Figure 4. Map of WAFB showing monitoring site locations.

Although emissions at WAFB were estimated to be higher than those at other USAF bases and detailed knowledge of WAFB operations was available, the need for preliminary data was recognized in order to design the air quality monitoring network and determine the type of meteorological measurements that would be required.

2.2 SHORT-TERM SPECIAL STUDY

A special study was conducted in an attempt to qualitatively delineate pollutant transport so that the number and locations of the long-term air quality monitoring stations could be determined. The study, "Ambient Air Analysis Survey at Selected Locations," was performed by the USAF, EPA, and ANL between April 1 and 18, 1975, and included three experiments (the third experiment was subsequently extended through June 18, 1975): (1) a grab-sampling effort by ANL at selected locations around the airport; (2) a single-jet impact study by EPA that included ANL bag sampling; and (3) an assessment by EPA to determine the adequacy of the Beckman 6800 CO and THC analyzer. This report covers only those data collected to aid in the design of the long-term study. (The data are also available in a draft EPA report, "Air Quality Data Collected by EPA/EMSL-LV at WAFB during the Short-Term April 1975 Airport Study," and portions are discussed in a paper on the overall USAF study [13]. For further study details, see Appendix B).

A static jet study, using a USAF T-38, was carried out on Saturday, April 5, 1975. This was done to obtain rough estimates of jet plume rise transport and initial exhaust-plume pollutant dispersion from the jet during engine idle and power modes of operation. Although estimates for jet plume rise and vertical and horizontal dispersion parameters are used for air quality calculations in current airport models, it was believed that these model parameters could be improved by actual measurement of jet exhaust-plume dispersion.

A visual concept of the experiment is presented in Figure 5. The sampling was done from an array of ground stations, established downwind of the T-38, at which 30-minute integrated bag samples were collected. Data were collected above ground level (AGL) from two 12.2-m towers and from an EPA H-34 helicopter air monitoring platform. Typical jet emissions during the experiment were calculated to be approximately 14 grams per second (g/s) CO, 4 g/s THC, and 0.5 g/s NO_x. Exhaust temperatures averaged 450°. Although the average WD during the experiment offset the sampling grid center line by 19°, the wind varied considerably during each 1/2-hour sampling period, providing representative pollutant samples. The two 12.2-m towers were located 100 m downwind, and samples were taken at these towers at elevations of 7.6 m and 12.2 m AGL. The average values for CO and THC (with background subtracted) are listed in Table 1.

The helicopter data were used to determine the vertical distribution of NO/NO_x, CO, temperature, and scattering coefficient (b_{scat} using a Meteorology Research Inc. ([MRI] integrating nephelometer). Passes were made at altitudes between 3.1 m and 42.7 m AGL at downwind distances varying from 0 to 200 m. Jet exhaust plumes were detected at 7 m AGL at 50 m downwind, 20 m

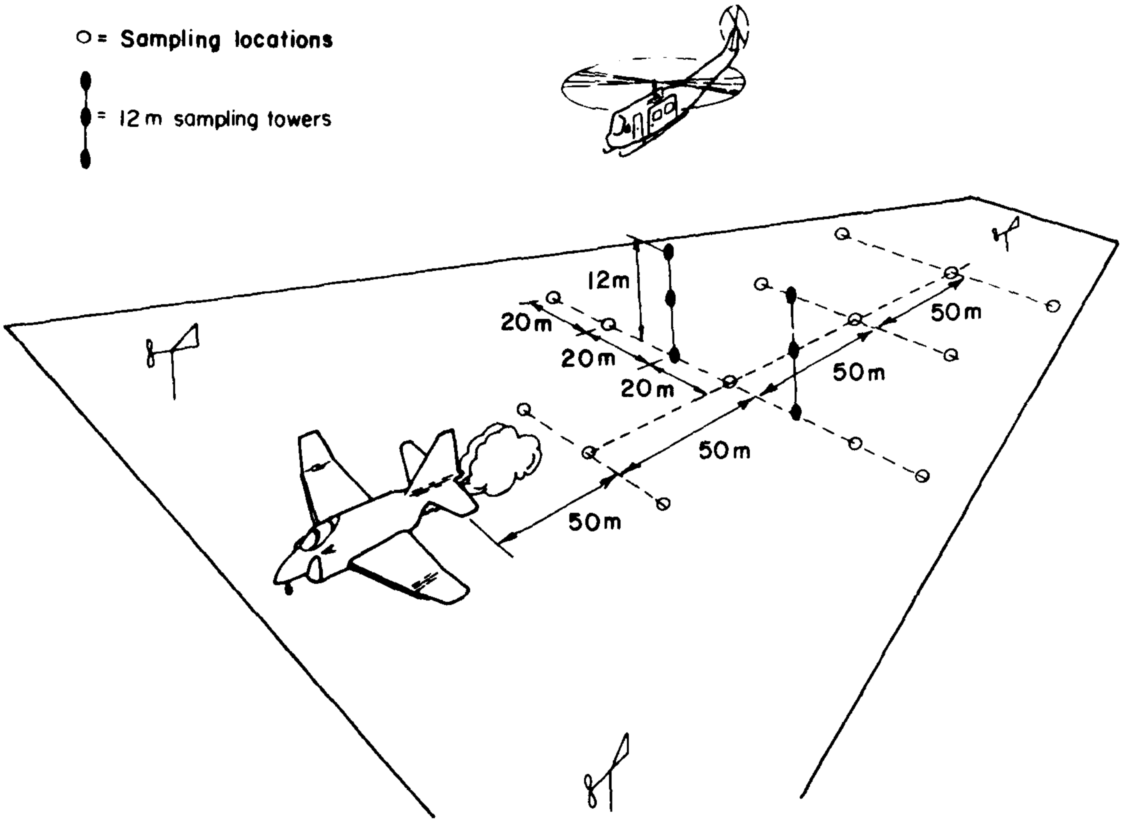

Figure 5. Sampling grid of single jet study at WAFB.

TABLE 1. AVERAGE CO AND THC CONCENTRATIONS
FOR STATIC JET BAG SAMPLES*

Vertical Location	Downwind Distance (m) 50	100	150	200
Ground (0.9 m)				
CO	17.7	2.0	3.2	1.0
THC	1.05	1.46	0.78	0.00
Tower (7.6 m)				
CO		3.9		
THC		1.84		
Tower (12.2 m)				
CO		3.6		
THC		0.00		

* These concentrations are in parts per million (ppm) and do not include helicopter data.

AGL at 100 m downwind, and 21 m AGL at 200 m downwind. (Results from this test led to an FAA exhaust dispersion experiment at Dulles International Airport that Recorded air quality data from several 100-foot towers downwind of taxiing aircraft.) Further detail on the helicopter measurements at WAFB can be found in Appendix B.

To assess the adequacy of the CO and THC analyzer and to determine the range of total suspended particulates (TSP), an Airstream trailer equiped with a Beckman Model 6800 gas chromatograph and a high-volume sampler was set up at site 1 of the subsequent long-term study (see Figure 4) to monitor ambient air continuously from April 9 to June 18. The aircraft emissions source area nearest to site 1 was the queueing area at the southeast end of runways 30C and 30R, south of the site. The high-volume samples revealed TSP concentrations ranging from 66 micrograms per cubic meter ($\mu g/m^5$) to 166 $\mu g/m^3$, indicating particulate loading in excess of the normal 45 $\mu g/m^3$ background concentration measured within a radius of about 25 km from WAFB. A short-term study was conducted between April 9 and 17 to measure THC concentrations. THC levels increased significantly during the evening of April 11 and from April 13 through 17. The highest value observed was 9.0 ppm at 0100, April 16. Throughout the rest of the sampling period, the THC levels were closer to the expected background level (worldwide background for THC of 1.42 ppm [14]). During this short-term study, there was considerable local agricultural activity, including chemical spraying, which could explain the higher levels of THC.

Pollution roses for CO and THC were constructed using April 17 - June 18 data, and the highest third of the concentration values were correlated with the WD values for each given month. The CO rose for May (Figure 6) represents all measured concentrations greater than or equal to 0.52 ppm, and it is representative of the other pollution roses. The highest pollution values recorded by month for each pollutant, the time each occurred, and the wind conditions at the time are given in Table 2. The peak concentrations listed in this table occurred during nighttime and early morning hours when aircraft activity was minimal and winds were predominantly from the southeast quadrant. The data in Table 2 suggest that, during nighttime and early morning hours, off-base sources produce greater concentrations of CO and THC at site 1 than do airbase flight activities.

The three parts of the preliminary ambient air analysis study provided pollutant concentration and distribution data and plume transport data for use in assessing the number and location of stations that would be needed to answer the technical requirements of the WAFB study. The preliminary study established a qualitative definition of dispersion and suggested plausible locations for monitoring sites for the year-long study.

The scope of this task to determine the location of sites included the need to monitor ground-level emissions from aircraft, and it was realized that plume rise may prevent measurement in the vicinity of emissions. Thus, consideration was given to transport and maximum downwind trajectories so that site locations would be far enough away from sources to allow emissions to disperse to the ground.

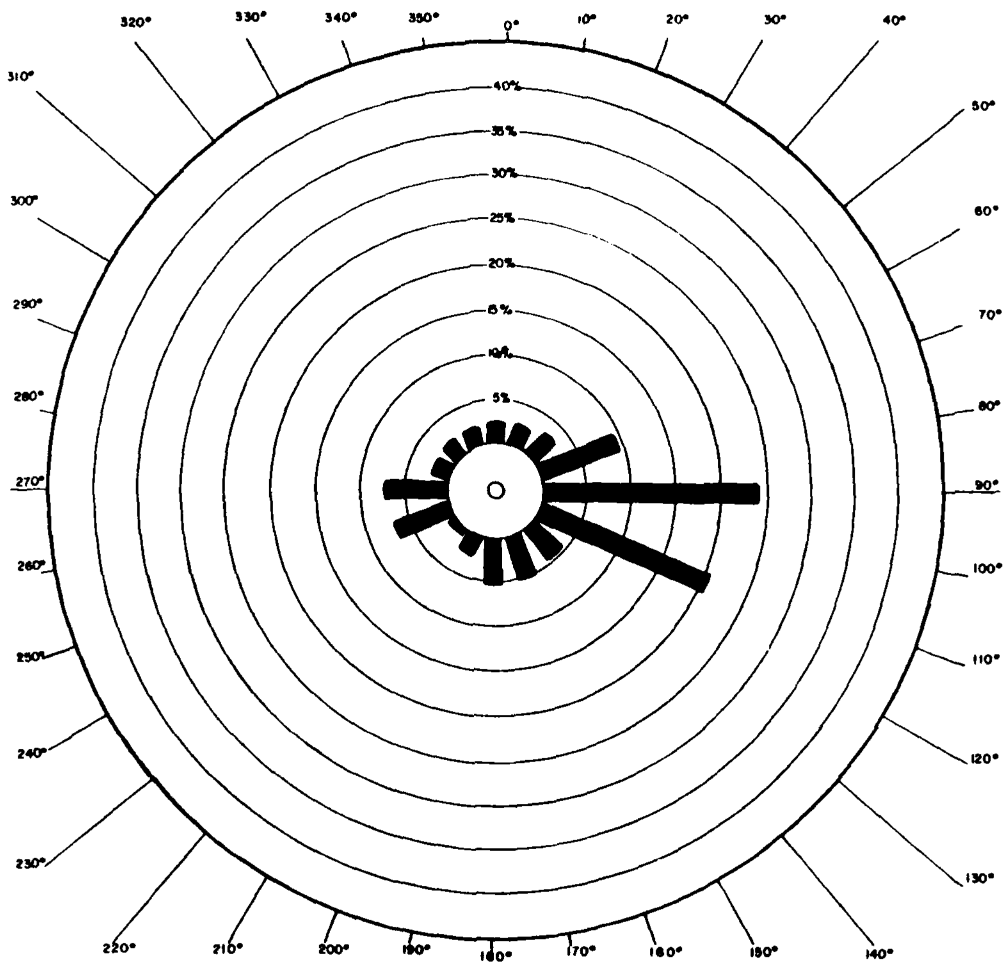

Figure 6. WAFB transmitter (site 1) CO pollution rose, May 1975 (concentrations greater than 0.52 ppm).

Local meteorology records were used to assess WD and its influence on potential (as well as known) source emissions in the WAFB area. Power and communications requirements, as well as aircraft flight-line safety constraints, were integrated into the final air monitoring network design. The locations for the five air quality and meteorology measurement stations were designated as shown in Figure 4. The criteria used in siting the stations are summarized in Table 3. Universal transverse mercator (UTM) coordinates, in kilometers, are included. Sites were selected to continuously monitor pollutant concentrations within areas of anticipated impact based on these preliminary data (Appendix B) and logistical considerations of flight patterns.

TABLE 2. SUMMARY OF HIGHEST HOURLY AVERAGES (BY MONTH) FOR THC, CH_4, AND CO DURING 1975 SHORT-TERM PRELIMINARY STUDY

Month	Highest Value (ppm)	Time Day	Time Hour	Wind Direction	Wind Speed
April					
THC	1.80	30	0000-0100	195°	4.0
CH_4	1.65	19	0400-0500	130°	2.5
CO	0.8	19	2100-2200	100°	3.0
May					
THC	2.80	22	2200-2300	105°	2.5
CH_4	2.70	22	2200-2300	105°	2.5
CO	1.02	10	0000-0100	90°	2.0
June					
THC	2.50	13	2300-2400	135°	4.0
CH_4	2.50	13	2300-2400	135°	4.0
CO	1.30	17	2000-2100	200°	11.5

2.3 CONTINUOUS MONITORING

Concentration levels measured during the April 1975 experiment indicated that high instrument sensitivity would be required to detect the lower concentrations and to monitor both the background levels and any large excursions of pollutant concentration. Requirements for calibration over this wide concentration range were also considered important since the assessment of AQAM accuracy relies in part upon the capability of discriminating between WAFB emissions that are in excess of background levels. It was confirmed from the ambient air analysis that CO, CH_4, NO, NO_x, THC, and meteorological wind speed (WS) and direction (WD) parameters would be measured continuously at each station. Light scattering (b_{scat}), an indirect measurement of particle mass concentration over a specific size range, would also be measured at each station. Other considerations in the selection of measurement instrumentation included the following:

- The instrumentation should already have a tested service credibility.
- The monitors must operate reliably over a long enough period to provide data for frequency distributions that are valid over a statistically acceptable time period.
- Calibration and drift from reference "true values" must be acceptable in order to eliminate excessive calibration adjustment that would reduce the percentage of recoverable data.

TABLE 3. SITING CRITERIA FOR FIVE AIR MONITORING TRAILERS*

Site No.	Location and Siting Rationale	UTM Coordinates X Position (km)	UTM Coordinates Y Position (km)
1	a. Southeast corner of base; northeast of runways b. Continuity with an April 1975 feasibility study c. Upwind during early and later morning periods d. Power already installed for April 1975 study	440.53	3685.06
2	a. Southeast corner of base; immed. northeast of runways b. Upwind of T-38 takeoff during morning period (99% of all takeoffs and landings at WAFB are southeast to northwest) c. Downwind of T-37 and F5 takeoff and taxi route for all aircraft during afternoon	440.12	3684.60
3	a. Southeast corner of base; immed. southeast of runways b. Downwind of T-37 queuing and takeoff during morning period c. Downwind of taxi segment for all aircraft during afternoon	439.29	3684.34
4	a. Near Building 16 b. Downwind of T-38 apron area during morning period c. Background to airfield operations during afternoon period	437.62	3685.29
5	a. Northwest corner of base; immed. off end of runway b. Downwind of all airport activities during morning period c. Downwind of taxi to shutdown for T-38's and F5's d. Background location for late afternoon and early evening		

* Aircraft in use at WAFB include the T-37 and T-38 trainers and the F5.

Instrumentation

The following measurement instrumentation was selected:

- Gas chromatograph with continuous flame ionization detector for THC, CH_4 and CO in the parts-per-billion (ppb) to ppm concentration ranges, a wide linear range, and a self-calibration feature

- Dual-reaction-chamber chemiluminescent analyzer for NO and NO_x in the ppb concentration range

- A nephelometer for light scattering in the visible wavelength (the measured scattering coefficient is then related to the visible range in the atmosphere.)

- WS and WD propeller vane sensors located approximately 8 m AGL.

Detailed instrument specifications are given in Appendix C.

Monitoring Stations

The five monitoring stations were trailer enclosures (2.5 m wide, 4.3 m long, 3.1 m high) containing air monitoring and meteorological instrumentation together with a remote data acquisition system. The five trailer data systems were connected to the central facility (located in Building 16) through dedicated telephone lines; separate lines provided voice communications between trailers and Building 16. Each monitoring station shelter was a Westinghouse Air Quality Mobile Enclosure housing the monitoring instrumentation (Figure 7). A heat/cool air conditioner was used to maintain a relatively constant trailer temperature.

The air sampling manifold for a monitoring station (Figure 8) included a glass ballast chamber upstream from the CO-CH_4-THC analyzer to provide a sample air residence time (ratio of volume to flow rate) of at least twice the data system interrogation rate (each minute of the hour). This chamber was procured and installed by the contractor after station interrogation rates had been determined in May 1976. The chamber allowed the averaging of transient high concentrations of CO, CH_4 and THC that would otherwise pass unobserved and accommodated the 5-minute sampling and analysis cycle of this analyzer. A separate 5-centimeter (cm) diameter inlet line, free of any angles, was made for sampling with the integrating nephelometer so as not to stratify the particulate sample prior to entry into the nephelometer.

Data Collection

The stations of the monitoring network were linked to a central data acquisition unit in Building 16. Each monitoring station was interrogated each minute of every hour. Stations 1 through 5 were polled each time in the same order. As the station was polled, the remote data system in each trailer scanned the voltage output of all air quality and meteorological sensors. Voltage from each station was then recorded on magnetic tape at the central data acquisition area. Time, trailer number, and operational status coding

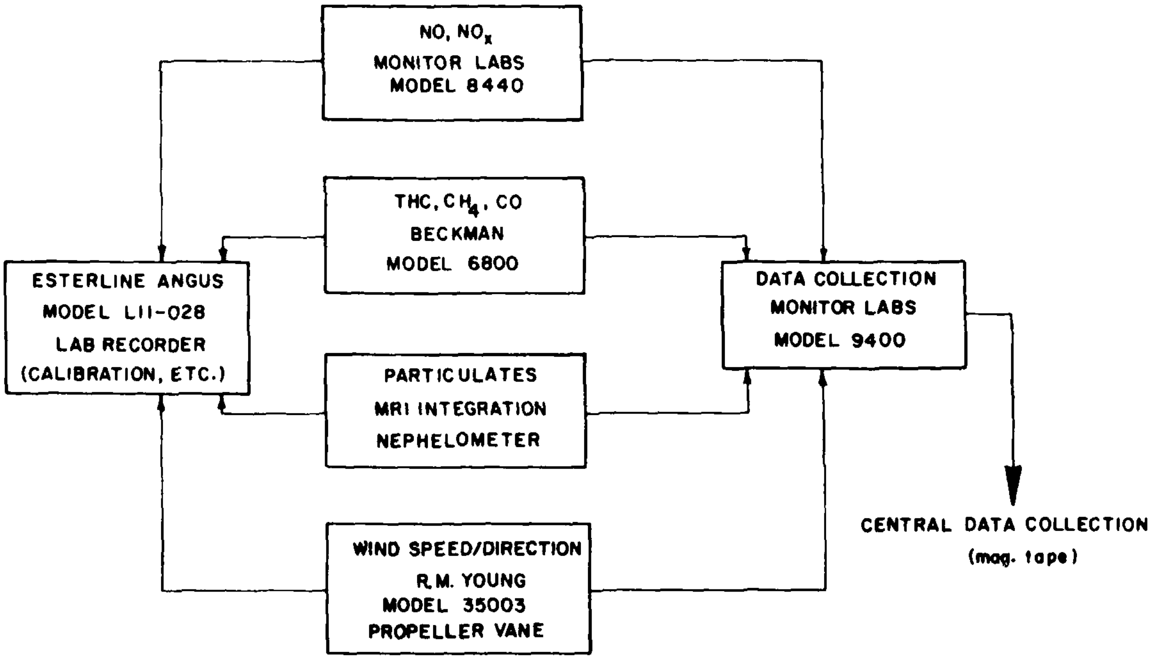

Figure 7. Block diagram of trailer instrumentation.

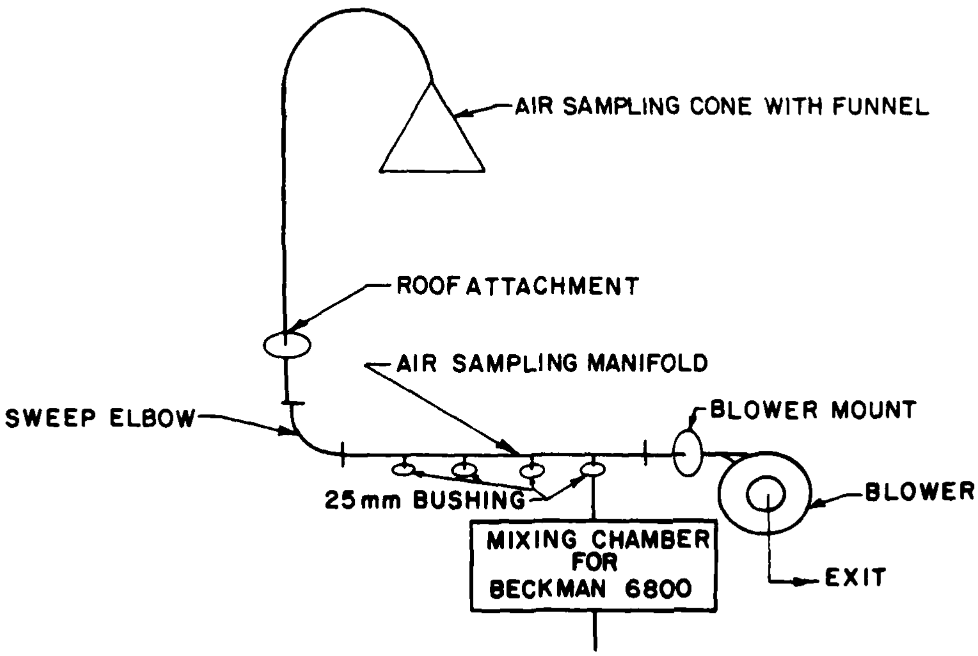

Figure 8. Air quality intake system.

for instruments and each data channel were logged for each air quality or meteorological parameter. The instrument basic to the central data acquisition unit was the Monitor Labs (ML) Model 9400. It digitized the analog output from the air monitoring instruments and transmitted the information to the central data system upon request (Figure 9). The system was equipped with 10 data switches that were used to transmit instrument status data according to thumbwheel codes at each station. Additional data acquisition system specifications are given in Apendix C.

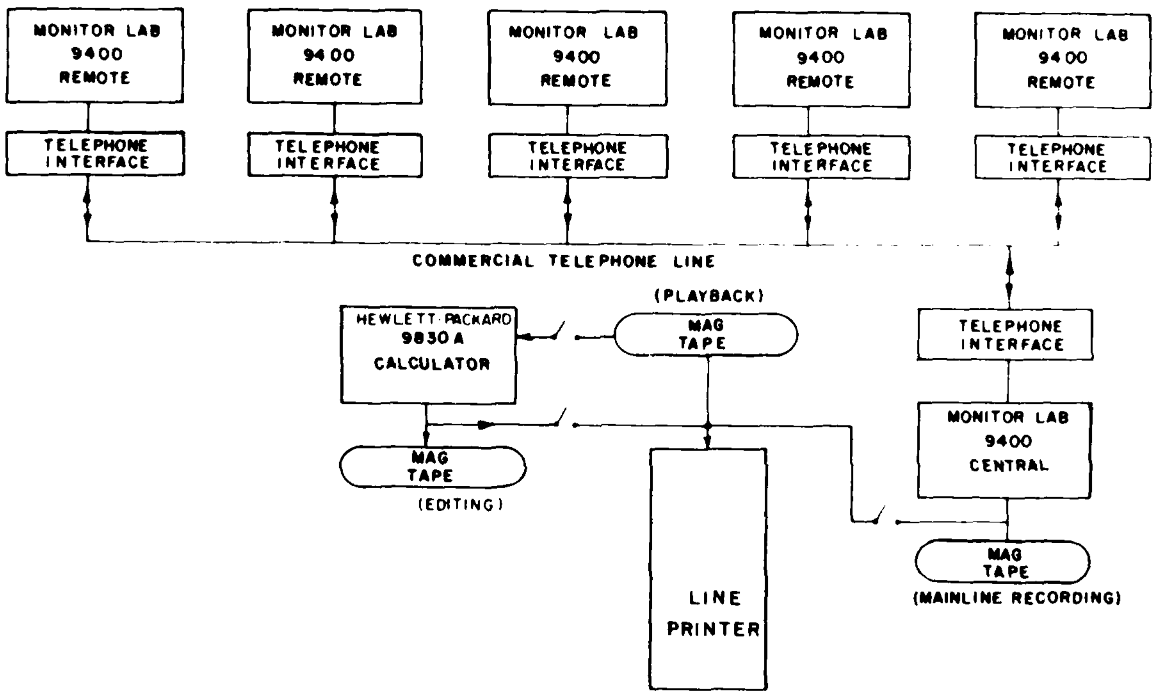

Figure 9. Data collection system.

2.4 ADDITIONAL METEOROLOGICAL INSTRUMENTATION

Additional meteorological instrumentation was used throughout the monitoring period. These included a pyranometer that collected data for most of the monitoring period at site 4, orthogonal wind sensors and temperature instrumentation installed in April 1977, an acoustic sounder operated continuously near Building 16 from June 1976 through June 1977, and boundary layer profile sensors. The sensors were used to provide further resolution of winds and temperatures in the vertical when compared to results from the acoustic sounder.

An Aerovironment Model 300 monostatic acoustic sounder was used to provide information from the interaction of acoustic waves with the atmosphere. These data indicated the various depths of the mixing layer and the time of inversion breakup (at the top of the mixing depth). They also provided information on the vertical mixing properties of the atmosphere and (as input for model calculations) insight into atmospheric stability. The control and recorder unit was located in Building 16, and the dish-shaped transmit/receive antenna was installed inside a trailer-mounted Model 301 acoustic enclosure (2.4 m high, pentagonal in shape) about 17 m west of Building 16. The recorder-acquired data and daily chart removal were timed to coincide with the magnetic tape changes or the calibration of monitoring stations.

A "u,v,w" propeller anemometer made by R. M. Young was installed at the top of the WAFB "boom" bucket tower (30 m high). An Environmental Systems Corporation delta temperature system, Model PTS-80A, was also installed. Data from these instruments are available from April 1977 through June 1977. These micrometeorological data were requested by ANL to provide them the opportunity to calculate stability parameters at WAFB in the event that data comparison showed model revision was necessary. Estimates of emission dispersion of parameters can be improved in the modeling phases of the study through the use of actual data characteristic of the atmospheric potential to disperse emissions.

Measurements with these meteorology instruments included one-minute orthogonal wind components (u,v,w) in the x,y and z directions and temperature and temperature difference over a 30 m vertical height.

2.5 MONITORING OPERATIONS

Monitoring operations and the quality control to maintain operations within acceptable limits were specified and monitored by EMSL-LV. Certain meteorological instrumentation was added to the study in June 1976, as described in subsection 2.4. A summary of all the instrumentation, calibration requirements, and the period of monitoring is shown in Table 4.

The monitoring trailers (stations) were constructed at WAFB with Government-furnished equipment under EPA contract and technical direction. The trailer system tabulation, installation, and integration to the data system were also done under EPA contract. The stations were operated by USAF technicians from the 6th Mobile Weather Squadron and by EPA contract personnel resident at WAFB.

Fabrication and assembly of the monitoring trailers took place at Building 16 at WAFB, located near site 4. When power became available in March 1976, the trailers were moved to their site locations and stabilized on jacks, and the air sampling manifolds were assembled. Overall system checkout and periodic maintenance and calibration activities began in May 1976, and data acquisition began in June 1976.

TABLE 4. INSTRUMENTATION SUMMARY

Parameters Measured	Instrumentation	Calibration Requirement	Period Covered
NO/NO_x	Monitor Labs 8440 (dual-chamber chemiluminescent)	• NO gas cylinder with 50 to 100 pm and dilution to 0.4 ppm • AADCo pure air generator • Low concentration cylinders 0.1-0.5 ppm	1 June 1976 - 30 June 1977
CO	Beckman 6800 (gas chromatograph with flame ionization detector)	• Gas cylinder with span concentrations from 3 to 5 ppm	1 June 1976 - 30 June 1977
THC, CH_4	Beckman 6800 (gas chromatograph with flame ionization)	• Gas cylinder with span concentrations from 3 to 5 ppm	1 June 1976 - 30 June 1977
Light scattering (b_{scat})	MRI model 1550B nephelometer	• Freon 12 cylinder and pure air from internal source	1 June 1976 - 30 June 1977
WS/WD	R. M. Young propeller vane	• Constant speed motor (1800 rpm, theodolite alignment on north, 13°30'E declination	1 June 1976 - 30 June 1977
Mixing depth	Aerovironment Model 300 acoustic sounder	• Independent measurements of temperature in the vertical	1 June 1976 - 30 June 1977
U,V,W (orthogonal winds, 30 m AGL)	R. M. Young Gill propeller vane	• Maintain electronics, constant speed motor (1800 rpm)	6 April 1977 - 30 June 1977
Solar insolation	Pyranometer	• Manufacturer's specification, EPA #126564 • Maintain electronics	*15 July 1976 - 25 January 1977 21 January 1977- 30 June 1977
ΔT	E.S.C. Model PTS-80A	• Calibrated by manufacturer	6 April 1977 - 30 June 1977

* Two sensors were used. Monitoring eriods were overlaped to check reproducibility.

Building 16 served as the onsite study headquarters where operations of the air quality monitoring network, data acquisition, preliminary data processing, and related special studies were coordinated. Laboratory operations, maintenance, administration, supply, and receipt of daily weather reports were also performed in this facility. Weather observations, essential to the AQAM model, were provided by: 1) USAF personnel using Federal Meteorological Form 1-10 (WABAN Form 10), "Surface Weather Observations"; 2) acoustic sounder codes; and 3) the WAFB weather station, which assembled data on a tape for the entire monitoring period.

Systems Performance

Before the beginning of the study, EMSL-LV specified the data record format to appear on the digital magnetic tape recorder and line printer. Also, digitized analog signals from the station instrumentation were demonstrated to be compatible with the digital data system of the ML 9400 central data acquisition unit. Systems performance was considered acceptable when:

- The analog signal inputs from air quality instruments and data switch (thumbwheel) information at each of the five monitoring stations was consistently interrogated by the central data system and reproduced on the mainframe digital-magnetic tape line printer.
- The central station could consistently poll or interrogate each monitoring station in succession.
- The digital characters on the line printer were the same as those transmitted from each data system, and nonvalid or misplaced characters did not appear in the recorded format.

The performance goal for WAFB air quality measurement was 80 percent recoverable data at the line printer.

The WAFB field operations were monitored by EPA during the two months prior to June 1976 to demonstrate that the five mobile stations and the central data acquisition system conformed to the original EPA plan. This inspection consisted of two parts:

1. Reviewing all trailers and central data acquisition equipment to ensure proper procedures for:
    - Stabilization of trailers
    - Physical mounting of instruments and auxiliary equipment
    - Electronic and electrical connections
    - Installation of ambient air sampling manifold
    - Safety practices and procedures

2. Demonstrating valid operation for the Beckman Model 6800 gas chromatograph, ML NO/NO_x analyzer, MRI nephelometer, Gill propeller vane, and ML data system through:

   - Calibration
   - Operation in the continuous mode for ambient air sampling
   - Accurate transmission of data from the data acquisition system as voltage printouts for air quality sensor responses to the central data ML 9400 magnetic tape.

The WS and WD instruments were aligned by Air Force (AF) personnel using a constant-velocity calibrator and theodolite. The AF took one tape of air sensor data for overall system evaluation and approved the EPA operating plans.

The station instrumentation was also evaluated in relation to previously established performance specifications for air quality parameters. These specifications included span and zero drift, range, and response or rise time (Table 5). Instrument manufacturers' performance specifications for the analyzers used at WAFB are given in Appendix C, and detailed calibration procedures are described in Apendix D. In the absence of any previous site-specific air quality measurements, it was anticipated that the analyzers selected would be adequate in the concentration ranges of interest.

TABLE 5. PERFORMANCE SPECIFICATIONS

	CO	THC and CH_4	NO and NO_x	b_{scat}	WS and WD
Range	0-10 ppm	0-10 ppm	0-.5 ppm	$0.1\text{-}10\times10^{-4}m^{-1}$	0-22 m/s 0-352°
Zero drift	± 5%/day	± 5%/day	± 5%/day	2%	
Span drift	± 5%/day	± 5%/day	± 5%/day	3%	
Precision	± 5%	± 5%	± 5%	4%	± 5%

Operations Procedures

The monitoring network at WAFB was subjected to a daily routine of maintenance and inspection. The operations procedures used to maintain the monitoring network are summarized in Table 6. The station inspection forms (Appendix E) were reviewed to identify out-of-tolerance conditions. Systems malfunction usually involved operator error with the data coding switches (thumbwheels) used in making the daily zero and span checks (see Appendix F).

TABLE 6. OPERATION AND CALIBRATION SCHEDULE FOR MONITORING NETWORK

Procedure	Schedule	Function
Trailer insection	Daily	Preventive maintenance to meet performance specifications
Zero and span check (unadjusted)	Daily	Monitor instrument status, trend, and drift; develop the calibration array to correct data
Calibration adjustments	One time per week, not to exceed 10 days	Reference to secondary standards to calibrate data
Maintenance	As required	Maintain operational status of sensors
Factory service	As required	Procurement and maintenance of manufacturers' specifications

2.6 QUALITY CONTROL

Quality control procedures at WAFB, in effect by June 19, 1976, consisted of detailed instruction (including calibration procedures) given to the USAF technicians and contractor personnel, the maintenance of standard reference gases, and recordkeeping for control charts. These procedures were implemented through daily inspection of the trailers and associated instrumentation; zero and span control checks, including a written record of unadjusted calibration values; and calibration corrections and adjustments.

Station Inspection

Air quality analyzers and meteorological instrumentation were operated 24 hours per day, 7 days per week, for the 13-month study. Monitoring stations were inspected each morning by the USAF technicians, using the Trailer Inspection Checklist (Appendix E). Experience showed that this was an appropriate schedule to maintain the operation of the network. Visual checks for physical damage to the station sensors and intake manifold, as well as status of station supplies (e.g., drierite, water levels, and strip-chart paper), were a part of this routine. Discrepancies were noted by the USAF personnel and brought to the attention of the resident contractor field engineer for corrective action. After the daily station inspection, a calibration term was dispatched to the monitoring site that had been selected for calibration. The daily inspection provided input for decisions made by

this team concerning changes in calibration (e.g., for a malfunctioning instrument).

Zero and Span Checks

The air monitoring instruments were checked daily to evaluate zero and span drift. During the zero and span checks, no attenuator adjustments were made on the instruments. The data were recorded on calibration check sheets, and the recorded data were tagged with a thumbwheel code in the data system so that the values could be retrieved during conversion of output voltages to pollutant concentration units (engineering units). These check values were used in the data processing operation for correcting data for zero and span fluctuations. The values were also used to construct control charts, which were analyzed to evaluate instrument performance on a continuing basis. The WS and WD instruments were not checked as frequently because of their reliability and simplicity.

Typically, one station was checked at a time. The order was altered from day to day so that a station was not checked at the same time on successive days. This helped to avoid systematic bias that could cause error in the collection of calibration check data. The procedures for this operation included a check of thumbwheel settings, wind azimuth, ML 8440 NO/NO_x analyzer, MRI nephelometer, and Beckman 6800 gas chromatograph. The step-by-step sequence is shown in Appendix E. USAF and contractor personnel recorded all the data from the calibration sheet onto permanent logbooks that remained at the stations. The positions of all the data switches on the calibration check sheet were also recorded for use in data processing.

Station Calibration

Once a day at the beginning of the study (and less frequently thereafter), the air monitoring instruments in each of the five stations were checked by USAF technicians, and adjustments were made to the zero and span calibration values. Initially, this calibration required up to 15 hours per day. Later, the frequency of adjusted calibration was specified for each air quality monitor, to occur at intervals of no less than 10 days, unless repair was called for (which would also require recalibration).

Daily site calibration was based on the following criteria:

- Instrument performance was indicated by the previous day's zero and span checks, as well as the results of the morning trailer inspection.
- Assuming no specific problems, trailer selection for calibration was made so that trailers were not calibrated on the same day of each week.
- Scheduling was arranged to ensure that a trailer went no longer than 10 days without calibration (see Table 6).

A wheeled cart containing the dilution calibration system was used to deliver calibration atmospheres at different concentrations for the NO/NO_x analyzer at each station. A mobile van was used to transport the Bendix Model 8851X

Dynamic Calibration System (BDCS), the AADCo zero air generator, Model 737, calibration gas cylinders (NO/NO_x), and compressors with silencer housing from site to site (Figure 10).

Calibration Gases

Air monitoring calibration gases, used in the production of test atmospheres for calibration activity, were obtained from certified vendors. Upon receipt of the gases, the vendor analysis was verified by cross-comparison to local gas standards, and the gases were subsequently cross-compared and analyzed at regular intervals to check for changes in concentration. The list of calibration gases, their use at each location, and dates of use are given in Apendix G.

In practice, the calibrations of the instruments were performed simultaneously and not as discrete steps. After the calibrations were completed, the instruments were allowed to stabilize. During this time the calibration values were recorded in logbooks provided for each instrument. The calibration sheets were maintained as a permanent record and were used to construct control chart graphs of instrument performance.

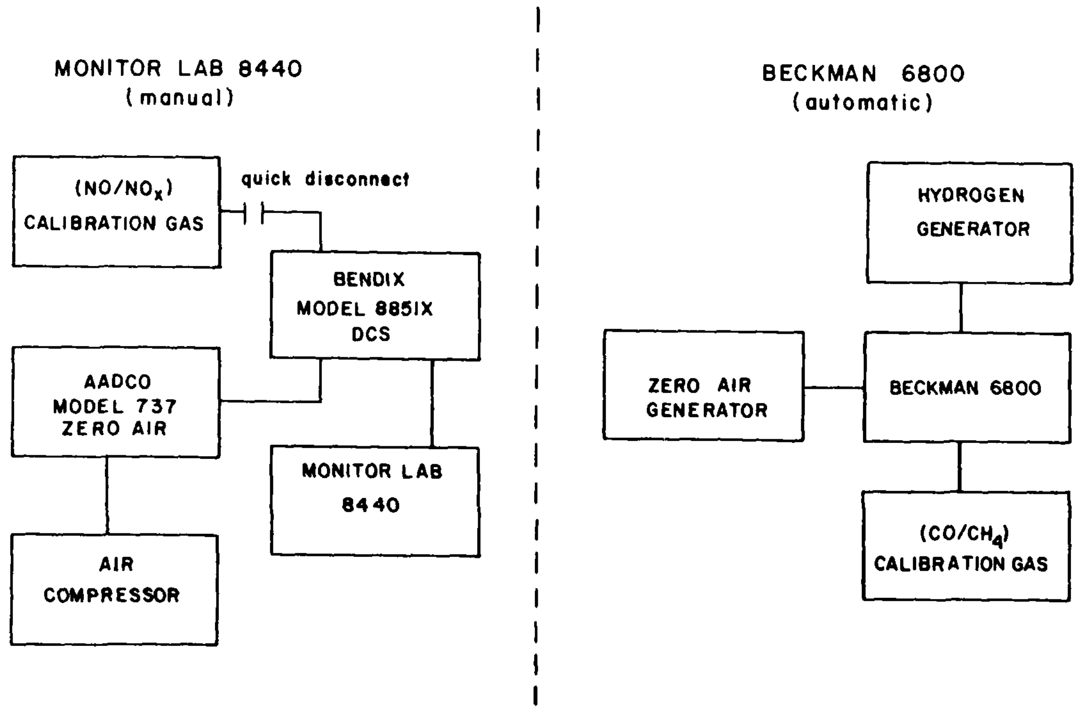

Figure 10. Calibration system for air quality trailers.

SECTION 3

DATA PROCESSING

Data processing activities for the WAFB project consisted of the following:

- Handling one-minute data tapes acquired from the air monitoring network (see Section 2) and verifying the contents of these tapes (Tape I)
- Calibrating the one-minute voltage tapes and converting the voltages to engineering units (Tape II)
- Averaging the one-minute data to produce hourly averages and calculating the root mean square average, the standard deviation, and the maximum and minimum for each hour (Tape III)
- Coding WABAN meteorological data onto computer forms and tape cartridges and merging this data into a data file of consistent format for each month that air quality data were collected (Meteorology Tape)
- Presenting data in the form of tabular listings of hourly data, frequencies, and cumulative frequencies of NO, CO, NMHC and nephelometer; cumulative frequency distribution plots of these four parameters; time plots of the hourly averages; time plots of minute values for four Julian days; and microfiche of the tabular listings
- Compressing 395 Level II tapes onto 20-reel set for future analyses

Digital voltage data from each of the five monitoring stations were recorded at one-minute intervals on magnetic tape in the central data acquisition facility (Building 16) at WAFB. Procedures were developed to convert the one-minute air quality data to hourly averages. The hourly-averaged data are presented in tabular summaries and monthly lots of concentration versus time. Data included the continuous air quality and meteorology data taken from the air monitoring network over a 13-month period. Processing required several levels of interactive editing with the use of control charts of zero, span, and calibration information to support data correction and adjustment. Checks for internal consistency were uniformly applied during data processing, and transmittal errors and rejected data have been identified in Appendix I.

Meteorology data collected as hourly observations on WABAN forms were coded by the USAF and provided on one magnetic tape. This tape also included the mixing-depth information from the acoustic sounder. Additional meteorology data collected at monitoring station 4 from April to June 1977 are

available on the one-minute magnetic tapes collected in the central data acquisition facility.

Data were accepted or rejected through editing, verification, and screening based on a predetermined set of criteria. The goal in processing was to assure that corrections were made for causes documented in operations logbooks for each monitoring station of the network.

The WAFB data were referenced to calibration standards at intervals as shown in Appendix G. Data from each monitoring station were referenced to transfer standards and also to primary standards to establish traceability to known concentrations as provided through the vendor. Uncertainty of calibration traceability was accomplished through vendor analysis and in-laboratory evaluation.

Prior to data processing, some data were examined to determine if they were representative and reasonable. Limits of acceptable analyzer values for a one-minute value (x) of each air quality parameter were specified as follows with regard to measurement concentration ranges encountered, instrument manufacturers' specifications, and measurement experience at WAFB prior to June 1976 (see the minute-to-hourly-average data reduction program in Appendix I):

NO:	$-0.05 < x \leqq 0.49$ (ppm)
NO_x:	$-0.05 < x \leqq 0.49$ (ppm)
CH_4:	$1.3 < x \leqq 7.9$ (ppm)
THC:	$1.3 \leqq x \leqq 7.9$ (ppm)
CO:	$0.0 < x \leqq 7.9$ (ppm)
NEPH:	$0.0 < b_{scat} \leqq 9.9$ ($10^{-4}m^{-1}$)

3.1 AIR QUALITY DATA

The air quality data base from the fixed monitoring sites, recorded in one-minute intervals, included data for CO, CH_4, THC, NO, NO_x, b_{scat}, WS and WD. NMHC data were obtained by subtracting CH_4 concentrations from THC concentrations (measured as CH_4), after the CH_4 and THC one-minute data had been converted to hourly averages.

The sequence of the data processing included the production of a series of four magnetic tapes, each a result of successive editing. Detailed procedures used for the production of these tapes are given in Appendix I. The four tape series included:

- Tape I Series - 395 seven-track tapes containing the raw one-minute air quality and meteorological data voltages acquired by the monitoring network stations as they were polled by the ML data acquisition system.

They are unedited and uncorrected and so include the effects of instrument calibration adjustments and instrument malfunctions. They also include data for periods of time when related special studies were being conducted during which the percentage of recoverable data was reduced. Voltage values for u,v,w and ΔT data are included in the record of monitoring station 4 for the three-month period from April through June 1977.

- Tape II Series - 395 tapes containing edited one-minute data as a result of performing the following processes on the Tape I data:

  - Extract calibration information.
  - Apply calibration and zero-drift corrections.
  - Convert from voltages to engineering units.
  - Remove any data known to be invalid as the result of instrument or operator error (as noted in station logbooks).

- Tape III Series - 13 tapes containing hourly averages and statistics computed from the one-minute data on the Tape II series. Each Tape III contains hourly averages for a complete calendar month.

- Meteorology Tape - One tape containing meteorology information transcribed from WABAN reporting forms summarizing weather observations at WAFB. Acoustic sounder u,v,w and ΔT data are appended to the WABAN information.

3.2 METEOROLOGY DATA

The meteorology data for WAFB were obtained from hourly WABAN observations coded by the USAF and produced separately from the air quality data record and from coding sheets listing acoustic sounder mixing depth. The meteorology data were then transferred to nine-track magnetic tape. The process for producing this tape is shown schematically in Figure 11. The tape format and character locations are shown in Appendix I. Meteorology data in the air quality data base were processed to become a part of the AQAM model input.

The acoustic sounder data were recorded on conducting chart paper, and daily chart removal was timed to coincide with the daily change of magnetic data tape (at 1,100 hours) from the air monitoring stations. This procedure facilitated the comparison of acoustic sounder and magnetic tape data and kept the acoustic sounder chart to a workable length for coding. Upon removal, each chart was trimmed to a uniform size and coated with a clear plastic spray to prevent smudging. Since the chart speed was not always uniform, the start and stop times and dates were written on each chart so that one-hour time marks could be located accurately. The time marks were drawn in for every hour on the half hour so that the average hourly acoustic sounding returns could be determined on the hour. The original records for the 13-month sampling period are maintained in Las Vegas.

The procedure for coding and placing the acoustic sounder data on the Meteorology Tape is presented in Appendix J. It allows the data user to sort

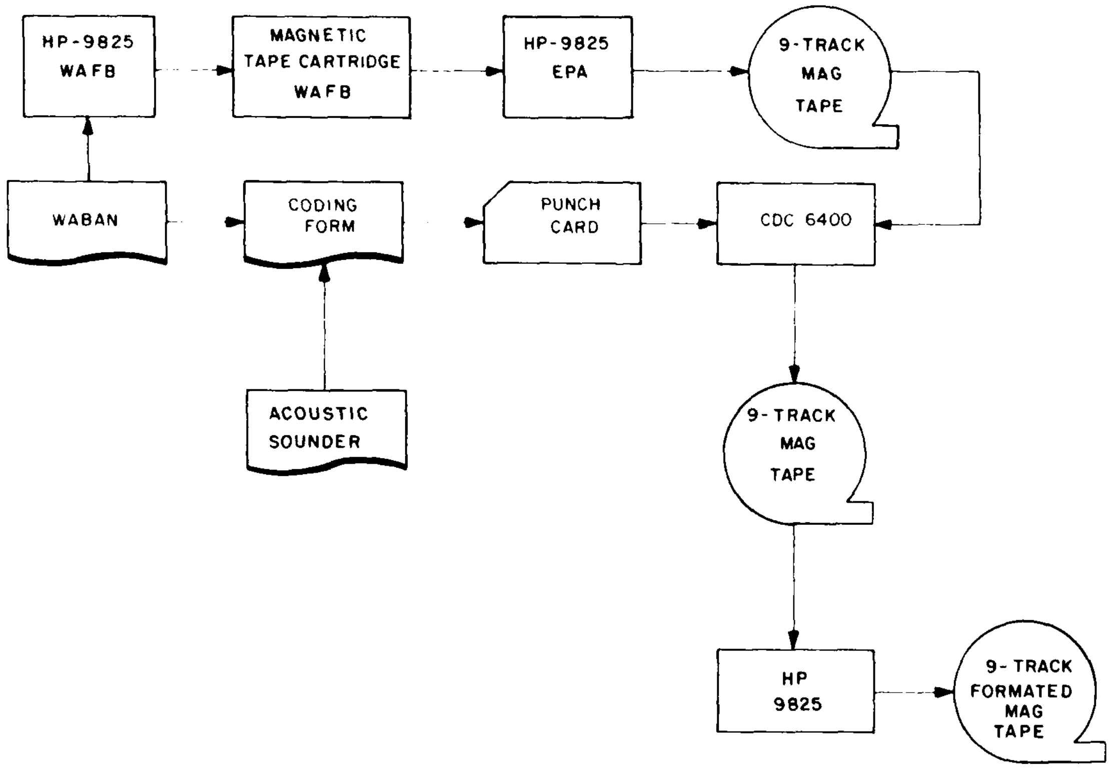

Figure 11. Base meteorology data processing steps.

the WAFB data according to various atmospheric conditions. Mixing depth is critically important to model calculations. The classification codes can be made specific to any study and locale. The six-digit code for each averaged hour indicates the phenomena observed -- for example radiation inversion, drainage winds, layered returns, lifting inversion base, subsidence inversion, frontal inversion, or normal daytime return. In addition, the heights of the various phenomena are listed.

The one-minute wind data from Tape I series (which were edited as a part of the Tape II process) were used to calculate one-hour wind averages for one-month increments (Tape III series). Final editing on the Control Data Corporation (CDC) 6400 Computer resulted in site-specific WD and WS for each of the stations for the entire monitoring period. Representative plots (Figures H-1 to H-91, Appendix H) show daily and monthly horizontal wind patterns. WS and WD studies with the Gill propeller vane sensors are discussed further in Appendix B, Related Special Studies.

3.3 DATA SUMMARIES

A complete 13 months of data from each monitoring station were tabulated in hour averages on the CDC 6400 and are archived at Tyndall AFB, ANL and EMSL-LV. Bound copies of these summaries will be maintained at Las Vegas until interpretation by the USAF and ANL is complete, at which time archival will be through microfiche only. The hourly-averaged concentrations for each air quality parameter are columned together with the daily average and the maximum for each 24-hour period. Irrecoverable data resulting from those periods when instruments were being calibrated, were inoperative, or were out of control because of operator error, as well as nonvalid data, are designated by 9's in the tabular summaries. The trailer data (generated in the following order: NO, NO_x, CH_4, THC, CO, NMHC, NEPH, WD, WS) consist of a total of 520 computer printout sheets.

The hourly averages for each of the air quality parameters were plotted for each month. These plots (Figures H-1 to H-91, Appendix H) show the hourly averages of each pollutant as well as daily and monthly horizontal wind patterns, for all trailer sites of the monitoring network on one page per month. They illustrate station-to-station variation of pollutant concentration and provide the user with the opportunity to select a time, a pollutant, or a section of particular interest for more detailed understanding and analysis.

The time series plots present one-minute data over a 24-hour period, and they allow the user to pinpoint the absence of, or effects from, aircraft emissions. Daily plots from September 28, 1976, December 29, 1976, January 27, 1977, and May 11, 1977, of the monitoring period are presented in Appendix H, Figures H-92 to H-134. These plots demonstrate excursions of pollution concentrations typical of the WAFB environment.

The locations of all data (tapes and tabulated data) are summarized below:

- Magnetic Tapes I (raw one-minute data) and II (edited one-minute data) are located at EMSL-LV.
- Tape III series (the corrected hourly averages for air pollutant, WS and WD data) are located at EMSL-LV and are also in the possession of ANL in Chicago, Illinois.
- Tabular summaries, cumulative frequencies, and graphics are located at Air Force Engineering and Services Center/RDVA, EMSL-LV and at the Tyndall AFB, Florida.

SECTION 4

DATA ANALYSIS AND EVALUATION

This section presents an analysis and evaluation of data obtained from continuous air monitoring at WAFB during the period June 1976 through July 1977. The purpose of this evaluation is to summarize data and assign appropriate limits for measurement accuracy (relative to average annual conditions). This summary will provide insight to the USAF contractor (Argonne National Laboratories) for use in performing the AQAM accuracy definition analysis.

To provide assurance of data validity, data were analyzed to determine confidence limits imposed by measurement precision. This was accomplished by reviewing calibration and calibration check data. Evaluation of the data base began by comparing the amount of air quality and meteorological data collected to that which would be sufficient to conclude that sampling had occurred during all representative meteorological conditions. Additional data analyses were performed to relate measured values to existing ambient air quality standards.

Estimates of measurement recision at WAFB in terms of pooled precision and calibration bias have been developed through reference to secondary standards for which statements of uncertainty have been provided by the vendors of calibration gases. Cumulative frequency distributions are presented in Appendix K to indicate the ranges of the data at each monitoring location and provide a graphical means for comparing relative measurement error between stations.

4.1 DATA RECOVERY

The percent-recovered data (shown in Table 7) account for 71 percent of the total time (pooled average) in the 13-month monitoring period. Tabular summaries of hourly averages for each air quality parameter (discussed in Section 3 and given in Appendix H) were produced from valid data tests that reduced the one-minute data recovery by about 10 percent. These data were discarded for the following reasons:

- They were out-of-tolerance, being outside the minium and maximum concentration range for the instrument sensor.
- They had errors resulting from systematic variations discovered in interactive editing (verified with operator and instrument logs).

TABLE 7. PERCENT DATA RECOVERY FOR FIVE MONITORING STATIONS OF WAFB STUDY

		(NO) NITRIC OXIDE	(NO_x) OXIDES OF NITROGEN	(CH_4) METHANE	(THC) TOTAL HYDROCARBONS	(CO) CARBON MONOXIDE	(NMHC) TOTAL HYDROCARBONS -METHANE-	(VMWD) VECTOR MEAN WIND DIRECTION	(VMWS) VECTOR MEAN WIND SPEED
June	1976	90.0	89.9	74.1	58.9	74.5	54.9	91.5	91.5
July	1976	89.9	89.9	71.4	70.6	74.5	69.2	93.1	93.1
August	1976	86.0	86.9	74.6	75.1	79.7	71.3	78.1	78.2
September	1976	59.1	59.5	70.3	70.5	70.7	69.8	74.6	74.6
October	1976	84.7	88.4	79.6	79.0	79.8	78.3	92.7	92.7
November	1976	76.2	81.2	68.0	72.9	70.5	68.0	70.2	70.2
December	1976	69.4	69.4	71.4	73.5	68.2	71.4	69.8	69.8
January	1977	56.2	52.7	61.1	59.8	62.1	58.8	51.1	51.1
February	1977	52.2	52.2	50.1	51.0	51.1	50.0	52.3	52.3
March	1977	45.7	45.3	44.5	45.4	45.6	44.0	48.0	48.0
April	1977	87.9	87.9	86.4	86.5	86.6	86.2	87.0	87.0
May	1977	72.7	73.7	72.2	72.5	72.2	72.2	74.5	74.5
June	1977	69.3	69.6	69.5	70.3	70.3	69.5	71.0	71.0
Total Average		72.3	72.8	68.7	68.2	69.7	66.4	73.4	73.4

Tabular summaries were examined to find out which monitoring stations were responsible for low recovery of data. This was done to confirm that data had been discarded for a reasonable cause. For example, station 1 of the monitoring network had a remote data system failure in May 1977 that was not repaired for the remaining period of monitoring. The highest data recovery took place in April 1977, and the station 1 data system failure reduced the percent recovery for the remaining months of the monitoring period.

Records for station 2 confirmed a problem in THC measurement for June 1976. Even though CH_4 and CO data were recovered at a level of 75 percent, THC and NMHC (THC minus CH_4) were less than 60 percent recovered. Logbook entries and troubleshooting notes confirmed that this instrument had valve and chromatographic column failures in this month. Wind sensor failure occurred at station 2 in January 1977, as supported by the station logbook entries.

Station 3 data recovery was greater than 70 percent throughout the monitoring period. Station 4 experienced about 70 percent downtime in February from data system failure. After the initial problems with the hydrocarbon monitor in station 5, data recovery was considered average (about 70 percent), with the exception of the January through March 1977 central data acquisition problem that affected all stations.

An analysis to show percent valid data capture on one-minute series tapes was not performed. However, one-minute data that did not meet one-hour average data processing requirements can be recovered from archived data (Appendix I). Monitoring operations and quality control procedures accounted for approxiately 16 percent interruption of one-minute data recording from the monitoring network.

Prior to monitoring, the time estimated for operational quality control and downtime for preventive maintenance was 8 percent. Capture of one-minute data at the line printer would have been about 92 percent if unscheduled maintenance, operator error, and data system failure had not occurred. Unscheduled maintenance for power, air-conditioning, and data system failure caused additional portions of the network to be inoperative an additional 8 percent of the time. Overall downtime was sampled from station logs for stations 2 and 3 and is shown in Table 8 to provide an example of system downtime during the monitoring period.

TABLE 8. SYSTEMS DOWNTIME AT STATIONS 2 AND 3

Operation	Percent Inoperable
Preventive maintenance (unadjusted checks)	4
Calibration (adjusted)	3
Power failure	3
Air-conditioning	4
Data system failure	1

The frequency of maintenance and repair was not fully anticipated, and replacement analyzers were necessary to avoid excessive downtime. High-maintenance problems are listed below in descending order of importance:

- Continued repair of NO/NO_x sensors, with high downtime for O_3 generators
- Hydrogen generator failure for CO, CH_4 and THC analyzers
- Power outages
- Air-conditioning failure, causing air quality instrument drift

4.2 WIND SPEED AND DIRECTION INSTRUMENT PERFORMANCE

The Gill propeller vane instruments used to collect the WD and WS data are highly reliable with a projected useful life of 2 to 4 years for WS and 3 to 5 years for WD under conditions of normal operation. Directional alignment at each monitoring station was established with a theodolite and checked twice with a sight compass, once during and once near the end of the monitoring period.

The wind azimuth range used was 0° to 352°, giving optimum linearity over the active range of the wind-direction scale. Zero and span instrument checks were done, although WD was not checked routinely. Estimates of the standard deviation of the wind direction instrument are one percent of the voltage output signal for azimuth during the monitoring period. Sight compass checks of sensor alignment indicated a repeatability of ±3° azimuth. WS was calibrated when instruments were replaced or repaired because of malfunction. These calibrations were performed with the USAF synchronous calibrator, and measurement uncertainty in WS is estimated at ±5 percent.

Table 8 shows that an average of 73 percent of the wind data were recovered for the monitoring period. Low January, February, and March recovery resulted from failure of the central data acquisition system. Recovery after April was affected by failure of the remote data system at station 1.

To compare the trailer WS and WD sensor output with that from the WAFB anemometer (as recorded on WABAN coding sheets), data from October 1, 1976, were examined. Since the station readings were instantaneous values recorded once per minute and the WABAN values were one-minute readings recorded hourly, correlations cannot be made by simply comparing the two measurements. As a result, readings from station 2 (in the proximity of the base anemometer) were averaged for 5 minutes before and 5 minutes after each reported time of WABAN measurement. These averages were then compared to the WABAN values for 23 hours on October 1. Graphs were constructed to display the results.

For WD data, the changes recorded at station 2 matched those of the base anemometer in terms of shift in direction (clockwise or counterclockwise), with a positive bias for the trailer values. The average station 2 value was

approximately 11 percent greater than the WABAN average for 23 hours (152° vs. 138°). As expected, there was consistent agreement for changes in WS although no high or low bias was observed in terms of wind speed magnitude. The average WS at station 2 was approximately 11 percent higher than the WABAN average for the same 23-hour period.

4.3 PERFORMANCE OF CONTINUOUS AIR QUALITY ANALYZERS

Analyzer Performance Characteristics

The principles of measurement utilized at WAFB are discussed in detail in Appendix C of this report. Further discussion is warranted regarding actual measurement precision and accuracy, particularly for the Beckman 6800 analyzer, which uses flame ionization detection to measure both total hydrocarbons and carbon monoxide as methane. The original monitoring objective for WAFB, established for modeling purposes, required the collection of useful ambient data over the full range of concentrations identified during the preliminary study performed by the EPA in 1975. This monitoring objective required the measurement of CO air quality levels below the minimum detectable limit of the EPA reference or equivalent method for CO, the nondispersive infrared principle.

Since jet and vehicular emissions at Williams AFB were to be monitored in terms of CO, NO_x, and hydrocarbons corrected for methane, the selection of measurement method was important. The gas chromatographic separation of CO, CH_4, and higher hydrocarbons (with subsequent analysis as methane) has advantages over other sampling and analytical procedures for these species. Hydrocarbons corrected for methane (reported as NMHC) are important in relation to oxidant formation although no NMHC standard is rigorously applied. A three-hour average (from 6 a.m. to 9 a.m.) of 240 ppb is a recommended guideline with respect to NMHC as precursors for photochemical oxidants.

Ambient atmospheres in the Western United States have annual mean CO concentrations of 200 ppb or less in nonurban areas, and concentrations as low as 50 ppb have been recorded in background areas [15]. The recognized procedure, which is sensitive at these concentrations, is to convert the CO to methane ad measure CO as methane with a flame ionization detector. Analyzer calibration requires sophisticated equipment and techniques. This procedure is incorporated in the EPA reference method for measuring NMHC as hydrocarbons corrected for methane.

However, unacceptable measurement discrepancies between various instrument configurations and different operators have been reported for this method of measurement. Variation between flame ionization detection hydrocarbon analyzers (when used to measure ethane, ethylene, and acetylene) have been observed to be substantial. The standard deviation for these variations in hourly-averaged NMHC data ranged from 217 to 454 ppb [16]. Therefore, to obtain useful data, additional quality control procedures were implemented for the gas chromatographs used at WAFB. In contrast to normal procedure where calibration is performed weekly, daily zero and span checks were made to control chromatographic separation efficiency and other routine operating

factors. This method, while still the most accurate for measuring CO according to EPA audit performance tests [17], has poor precision for NMHC. However, in the concentration range of interest at WAFB, there was no other method suitable for use in monitoring previously observed levels for hydrocarbons or CO.

Measurement uncertainty (in terms of precision) for the CO and hydrocarbon analyzer used at WAFB is less than that published in other reports. Daily calibration checks were responsible for the relatively good precision. Additional technical data were collected in the laboratory using the analyzer from station 1 at WAFB to develop repeatability precision at concentrations comparable to those encountered during monitoring. These data indicate that analyzer performance for the Beckman 6800 will exceed published limits when the instrument is operated under controlled conditions similar to those imposed at WAFB.

Operation of the station 1 Las Vegas analyzer in the laboratory was identical to that at WAFB. Test atmospheres of CH_4 were introduced at levels of 3.0, 1.5, 1.0 and 0.0 ppm. Standard deviations of calibration were determined to be 0.014, 0.006, 0.003 and 0.001 ppm, respectively, over a four-day period. Repeatability precision (average) at the 95 percent confidence level for THC and CH_4 response to methane was found to be 0.016 ppm, and precision for hydrocarbons corrected for methane was 0.023 ppm. CO test atmospheres were introduced to the analyzer at 3.0, 0.2 and 0.0 ppm. Standard deviations observed were 0.02, 0.01 and 0.006 ppm, respectively, and average precision for CO was 0.046 ppm. This relatively high precision can be attributed to the laboratory environment, operator skill, calibration apparatus, and techniques used. Based on the annual average air quality levels measured at WAFB, these results indicate laboratory precision as shown:

CO	$\pm$ 0.046 ppm, or $\pm$ 23.5 percent
CH_4	$\pm$ 0.016 ppm, or $\pm$ 0.98 percent
THC (as methane)	$\pm$ 0.016 ppm, or $\pm$ 0.93 percent
NMCH (HC corrected for methane) derived	$\pm$ 0.023 ppm, or $\pm$ 17.7 percent

These precision estimates apply at the 95 percent confidence level, and they are referenced to the annual average pollutant concentrations measured at WAFB.

The persistent low concentrations measured in the WAFB project tested the state of the art of the air quality analyzers and calibration techniques used. Most continuous air quality instruments were developed to operate in urban environments for enforcement purposes or to record ambient concentrations that are midrange or higher. Concentration levels of CO, NO/NO_x, and THC at WAFB were consistently below national norms for urban environments; therefore the sensor responses as related to signal-to-noise ratio and lower limits of detection had to be determined prior to data processing. Analyzer

concentration and nephelometer values were examined to determine if they were representative of instrument and calibration performance. This was difficult because very little monitoring of the type needed to evaluate models had been conducted at the low concentrations of the Williams AFB area. To screen data from the monitoring network, criteria were used from related experience, manufacturers' specifications, and calibration and measurement experience from the five monitoring stations.

Measurement Precision and Accuracy for WAFB Data Base

A summary of 12-month annual average concentration values and measurement standard deviations for the WAFB data base is given in Table 9. These values were determined directly from the data base, and they were utilized to estimate the accuracy limits for the air quality analyzers used at WAFB.

TABLE 9. SUMMARY OF AIR QUALITY PARAMETERS AT WAFB

	12-Month Annual Average and Standard Deviation of Measurement				
	STATION				
Parameter	1	2	3	4	5
CO (ppb)	141	167	121	361	195
SD[a]	90	120	110	100	100
NMHC (ppb)	82	137	106	225	99
SD[a]	100	160	122	146	78
THC (ppm)	1.66	1.70	1.67	1.88	1.72
SD[a]	0.07	0.05	0.07	0.08	0.05
CH_4 (ppm)	1.61	1.62	1.60	1.67	1.66
SD[a]	0.07	0.15	0.10	0.12	0.06
NO_x (ppb)	11.0	12.0	13.0	20.0	12.0
SD	10.0[b]	10.0[b]	10.0[b]	17.0[a]	10.0[b]
NO (ppb)	3.0	3.0	3.0	6.0	4.0
SD	10.0[b]	10.0[b]	10.0[b]	14.0[a]	10.0[b]
b_{scat} (10^{-4} m^{-1})	0.55	0.60	0.61	0.58	0.58
SD[b]	0.18	0.18	0.18	0.18	0.18

[a]Standard deviation estimated from calibration data
[b]Standard deviation estimated from manufacturers' specifications

The standard deviations for 12 months of calibration data (daily checks and biweekly calibration adjustments) have been combined with precision data to estimate measurement accuracy. Estimates of multiple-station precision have been developed by averaging the squares of the standard deviations shown in Table 9, assuming normal distribution of data away from the mean span concentration. However, statistical tests to choose units that best approximate the Gaussian normal distribution of the calibration data have not been performed. Should precision estimates be needed for time periods shorter than 12 months, a station-to-station comparison of hourly pollutant averages is recommended using calibration data from Appendix G for the specific period of interest.

The accuracy of instrumental measurement has been estimated through the traceability of calibration materials (secondary standards used at WAFB) to primary standards listed in Appendix G. Analyzer calibration was performed at only one (span) point. Therefore, analyzer linearity was determined only through manufacturer's procedures, and precision data derived from the calibration data should not be used indiscriminately. Estimates of measurement accuracy derived from instrument standard deviations do not include sampling variability that can result from manifold (probe) effects nor do they include measurement bias that can result from station orientation or wind direction.

Based upon the calibration data recorded in Appendix G, the following estimates were derived for calibration gas accuracy as determined by comparison of the WAFB trailer gas cylinders (calibration standards) to known reference materials (National Bureau of Standards (NBS) traceable cylinder gases maintained in Las Vegas and at NSI laboratories at Research Triangle Park, NC):

CO	3.00 ± 0.46 ppm
CH_4	3.00 ± 0.12 ppm
NO	0.42 ± 0.042 ppm

These estimates reflect a range of two standard deviations at the 95 percent confidence level, and they assume that the primary standards are within $\pm$ 0.04 ppm of the "true" concentration (traceable to NBS).

Estimates of the calibration bias were prepared by determining the percentage deviation of the stated calibration values from the "true" values. This percentage deviation was then multiplied by the annual average pollutant concentration to yield an estimate of the calibration bias. This procedure relies on the assumption that the same percentage calibration errors apply at both the span gas concentration and the annual average measured value. Since no multipoint calibrations were performed at WAFB, this assumption cannot be supported rigorously.

Using these estimates of calibration bias and the precision standard deviations given in Table 9, estimates were prepared for the overall measurement bias (accuracy) encountered at WAFB. Station-to-station variation

was averaged by "pooling" the individual station precision standard deviations using:

$$\sqrt{\frac{\sum_n (SD_n)^2}{n}}$$

where SD_n = individual station precision standard deviation and
n = 1, 2, 3, 4, 5.

These "pooled" precision estimates were then combined with the calibration bias to yield an estimate of overall analyzer bias (accuracy) using the following relationship:

$$\text{overall bias} = \sqrt{(\text{pooled precision})^2 + (\text{calibration bias})^2}$$

Since THC and NMHC (hydrocarbons corrected for methane) were determined as methane, the calculation for overall bias for these parameters assumes that their calibration bias is the same as that for methane. This assumption naturally disregards any consideration of the conversion efficiency of the Beckman 6800, and it implicitly assumes that all nonmethane hydrocarbon species present at WAFB were converted to and measured as methane. The Beckman 6800 is discussed further in this section.

The following chart summarizes the results obtained from previously described precision and accuracy calculations (all values are given in ppm units):

PARAMETER	POOLED PRECISION	CALIBRATION BIAS	OVERALL BIAS
CO	0.1045	0.03	0.109
CH_4	0.1053	0.025	0.108
THC	0.0661	0.023	0.07
NO	0.0109	0.0004	0.0109
NO_x	0.0117	0.0014	0.0118

Measurement accuracy limits were estimated by dividing the overall bias by the geometric average of the annual average concentrations shown in Table 9. This procedure yielded the following results for measurement accuracy limits:

CO	$\pm$ 55 percent
CH_4	$\pm$ 6.6 percent
THC	$\pm$ 4.1 percent
NO	$\pm$ 287 percent
NO_x	$\pm$ 109 percent

Since no calibration was performed with a hydrocarbon standard that did not contain methane, the accuracy limits for NMHC measurement (difference between THC and CH_4 values) may be estimated by root mean square addition of

the overall bias results for CH_4 and THC. This results in an estimated overall bias of 0.129 ppm and accuracy limits of ± 99.4 percent for the NMHC values reported from this study.

Similarly, the accuracy limits for NO_2 measurement (difference between NO_x and NO values) may be estimated by root mean square addition of the overall bias results for NO_x and NO. This results in an estimated overall bias for NO_2 of 16.1 ppb (0.0161 ppm). When compared to the annual average NO_x concentration of 10.8 pb, this leads to an estimated NO_2 accuracy limit of ± 149 percent.

Repeatability Data for Beckman 6800 Analyzers

Although multipoint calibration and external performance audits were not conducted on the continuous analyzers used at WAFB, an extensive body of quality control data was recorded from daily zero and span checks and biweekly calibration checks and adjustments. These data have been evaluated to provide a measure of analyzer precision (repeatability). This information becomes significant because annual average pollutant concentrations measured at WAFB were well below national standards and were, in many cases, at or near the analyzer threshold sensitivity. The following material is presented to support previous estimates of instrumental measurement accuracy and to document the actual performance of the Beckman 6800 analyzers at low pollutant concentration levels.

The Beckman 6800 multicomponent CO/CH_4/THC gas chromatograph is essentially three instruments in one integrated unit using flame ionization detection to measure each component as methane. Separate electronics for each component amplify the air quality signal transmitted to the data acquisition system. Each amplifier requires both electronic and chemical fine tuning in order to provide calibrated output. (See Appendix D for detailed calibration procedures.)

The Beckman 6800 analyzers were operated on the 0-10 ppm concentration range. Cylinder gas methane standards were used to check the calibration of the CH_4 and THC components when daily zero and span checks were performed. Standards with CH_4 concentrations at midrange and lower were selected for span gasses since analyzers normally measured background and low concentrations of both CO and THC.

The degree of control exercised to monitor span drift of the Beckman 6800 is illustrated in Figure 12. This control chart, for October 1976 at station 3, shows unadjusted span drift and calibration changes as monitored through the daily checks. The secondary standard concentration in use at station 3 during this period was 4.98 ppm for CO and 5.11 ppm for CH_4.

Acceptable span drift limits had been set at ± 5 percent of full scale (or 0.5 ppm) for any 24-hour period (Appendix C). Data presented in Figure 12 indicate that the analyzer was within acceptable limits for most of October. However, span drift recorded during the check on October 25 resulted in station calibration adjustments.

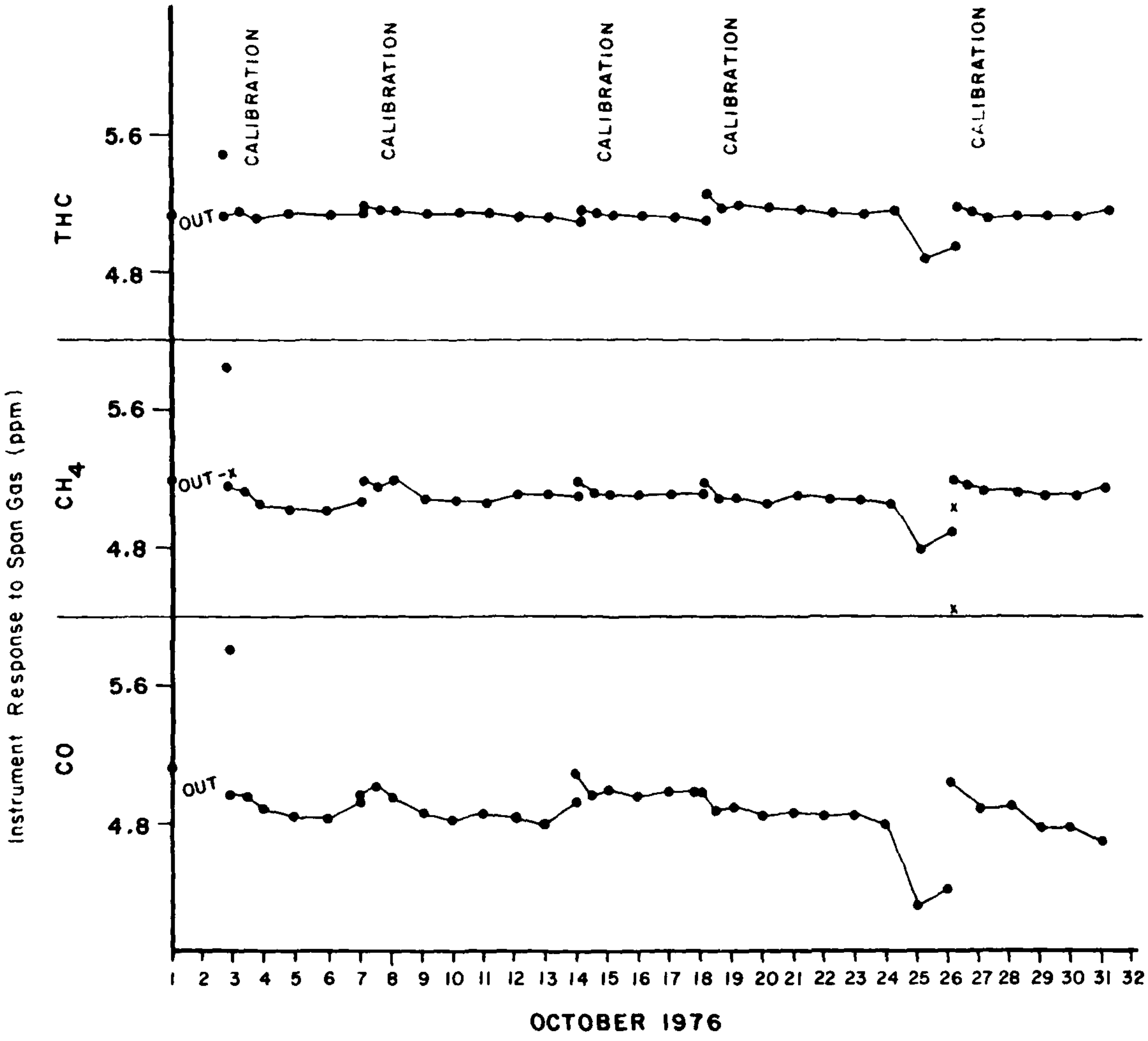

Figure 12. October 1976 control chart for the Beckman 6800 analyzer at station 3.

The pooled estimate of precision for CO measurement is expressed as two times the pooled standard deviation derived from data in Table 9. Multiple station analyzer precision for CO (at the 95 percent confidence level) is estimated at 2(0.1045) ppm, or 0.209 ppm. An EPA summary [17] of audit performance for Beckman 6800 CO measurement at a level of 3.43 ppm reported a mean measurement of 3.57 ppm with a standard deviation of 0.62 ppm. The WAFB CO measurements have better precision by comparison because daily zero and span check information was maintained as a control on instrument performance.

Data from Table 9 were used to derive an estimate for measurement precision of NMHC (hydrocarbons corrected for methane), which was recorded as the difference between THC and CH_4 concentrations. Standard deviation data from both THC and CH_4 calibration spans were combined to derive a measure of NMHC precision, assuming that each channel's standard deviation was due to independent sources of variation:

$$
\begin{aligned}
SD_{NMHC} &= \sqrt{(0.06612)^2 + (0.1053)^2} \\
&= 0.124 \text{ ppm}
\end{aligned}
$$

Measurement precision for NMHC is then estimated at two times the standard deviation (at the 95 percent confidence level), or approximately 0.25 ppm.

Measurement Precision for NO/NO_x

Acceptable limits for NO analyzer performance were set at $\pm$ 5 percent of full scale ($\pm$ 0.01 ppm) prior to the start of monitoring, in conformance with manufacturer's sensitivity specifications. Tests for acceptable quality control were made with control charts for NO and NO_x such as those presented in Figure 13 for station 5 during April 1977. Span value variation during this period is estimated at 0.004 ppm. The data presented in Figure 13 show that station 5 was within tolerance for April and document corrective action taken to correct trends toward out-of-tolerance operation.

Zero drift for the NO analyzer at station 4 varied from 1 to 5 ppb. Analyzer precision at station 4 for the 13 months of operation is estimated at 0.034 ppm for NO_x at the 95 percent confidence level (two times the measurement standard deviation shown in Table 9) exceed the annual average NO concentrations by 2.5 to 3 times at all five stations. This has led to placement of unusually large accuracy limits ($\pm$ 287 percent) on the NO values reported.

The eight secondary NO calibration standards used at WAFB were cross-compared to an NBS NO standard cylinder in February 1977 (Appendix G). Nominal concentration data supplied by the vendor was compared to the NBS value, and a calibration bias was obtained by pooling the uncertainties of the secondary standards with those for the NBS material through cross-comparison. The calibration bias for NO is estimated at $\pm$ 10 percent of the nominal 0.42 ppm secondary standard concentrations.

Measurement Accuracy Limits for Scattering Coefficient

As part of the daily station zero and span checks, the integrating nephelometers were checked for response to filtered pure air and internal "calibrate" reading (a measure of deviation in the instrument optical signal path). During calibration, both zero air and Freon 12 were introduced to the instrument, and appropriate adjustments were made to bring the instrument response to 0.23 $(10^{-4})m^{-1}$ and 3.6 $(10^{-4})m^{-1}$, the accepted b_{wcat} values for clean air (at sea level) and for Freon 12, respectively. No correction was made to account for the altitude of WAFB, 422 m above sea level.

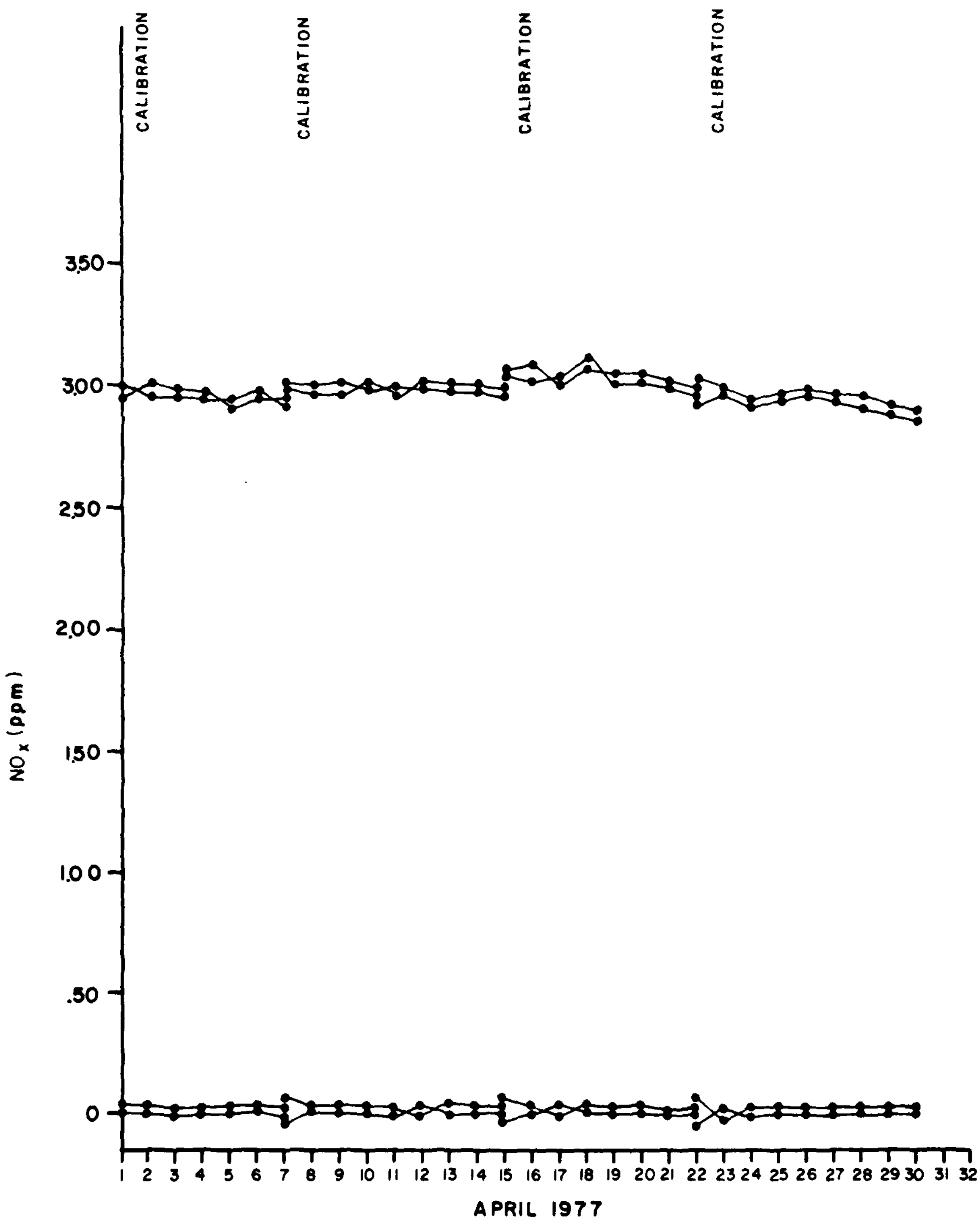

Figure 13. April 1977 NO/NO_x control chart for station 5.

As a result of the daily zero and span check and calibration procedures, performance data were recorded for unadjusted response to clean air and for adjusted response to clean air and Freon 12 (span). Since no values were recorded for unadjusted span response, the instrument span drift cannot be determined. However, zero drift and the variation in adjusted response values can be used to calculate a measure of instrument precision based on assumed true b_{scat} values for the zero and span gases -- 0.23 $(10^{-4})m^{-1}$) and 3.6 $(10^{-4})m^{-1}$, respectively. These calculations were performed for station 1 for a random sample of five months and resulted in the following:

Standard deviation of instrument span response (adjusted)	0.12 $(10^{-4})m^{-1}$
Standard deviation of instrument zero response (adjusted)	0.033 $(10^{-4})m^{-1}$
Standard deviation of unadjusted zero response	1.20 $(10^{-4})m^{-1}$

The standard deviation for adjusted zero and span variation may be pooled to yield an estimate of the calibration bias as follows:

$$\text{calibration bias} = \sqrt{(0.12)^2 + (0.033)^2}\,(10^{-4})m^{-1}$$
$$= 0.124\ (10^{-4})m^{-1}$$

Since no record was made for unadjusted span response, the variation in unadjusted zero response must be used as a measure of the instrumental precision. This is not a bad assumption since the annual average b_{scat} value at station 1 was 0.55 $(10^{-4})m^{-1}$ (Table 9), which is very close to the instrument zero of 0.23 $(10^{-4})m^{-1}$. Therefore, when this precision standard deviation is combined with the calibration bias, an overall measurement bias for b_{scat} is determined to be:

$$\text{overall bias} = \sqrt{(0.124)^2 = (0.20)^2}\,(10^{-4})m^{-1}$$
$$= 0.235\ (10^{-4})m^{-1}$$

This overall bias results in an estimate for measurement accuracy limits of $\pm$ 42.7 percent, based on the annual average concentration value.

Research has shown that a correlation exists between scattering coefficient and mass concentration for atmospheric particulates. In cases where local atmospheric aerosol can be characterized in terms of particle size, number, and mass distribution, nephelometer b_{scat} values can be related to aerosol mass concentration, provided care is exercised in extending the scattering coefficient over time and space. Urban ambient aerosols require extensive study in order to characterize their physiochemical light scattering properties and to relate them to a b_{scat} measurement.

A four-day special study was conducted at WAFB to characterize the local ambient aerosol. However, analyses were performed only on particles in size

ranges greater than 2 micrometers (μm) in diameter, and no consistent relationship was established to the nephelometer b_{scat} values, where light scattering is recorded for particles in the 0.5 to 1.5 μm size range. A complete report on this special study may be found in an Illinois Institute of Technology Research Institute (IITRI) publication [22].

By assuming the existence of an average size distribution that remained constant during the monitoring period, it is possible to estimate a relationship between mass concentration and light scattering measurements made at WAFB. Tomback [27] presents details of a correlation established by Charleson and Ahlquist which states that, for cases where particle size distribution and specific gravity remain constant with time, the following approximate proportionality applies between mass concentration (in grams per cubic meter (g/m^3) and b_{scat} (in m^{-1}):

$$\text{mass concentration} = 0.45^{+0.45}_{-0.22}\ b_{scat}$$

Based upon this relationship, mass concentration (in μg/m^3) and b_{scat} (in 10^{-4}m^{-1}) may be related by:

$$\text{mass concentration } (\mu g/m^3) = 45^{+45}_{-22}\ b_{scat}\ (10^{-4}m^{-1})$$

Using this mechanism, the annual average b_{scat} recorded at station 1 -- 0.55 $(10^{-4})m^{-1}$ -- translates into an estimated mass concentration of $24.75^{+24.75}_{-12.1}$ μg/m^3, an extremely low value in comparison to observed urban values and the primary National Ambient Air Quality Standard (NAAQS) of 160 μg/m^3.

4.4 REPRESENTATIVE METEOROLOGICAL CONDITIONS

The representativeness of the meteorological data collected at WAFB is important to the definition of the accuracy limits of AQAM and the interpretation of air quality data in terms of evaluating the impact of airbase operations on air quality. The data set collected at WAFB meets the minimum monitoring requirement of one year commonly imposed to ensure that monitoring occurs during all representative wind conditions. However, five years of representative meteorological data are normally preferred to minimize year-to-year meteorological variations. The representativeness of the WAFB data base was tested by summarizing 12 months of data for wind direction and speed for the five monitoring sites and then comparing these data to the historical wind rose (see Section 1.3 and Figure 3). Data acquired at WAFB appears to be representative of typical annual meteorological conditions.

Meteorological data were assembled into frequency distributions according to WS and 16 classes of WD (in increments of 22.5°) for the five stations. Figures 14 through 18 present WS and WD in the form of wind-rose diagrams.

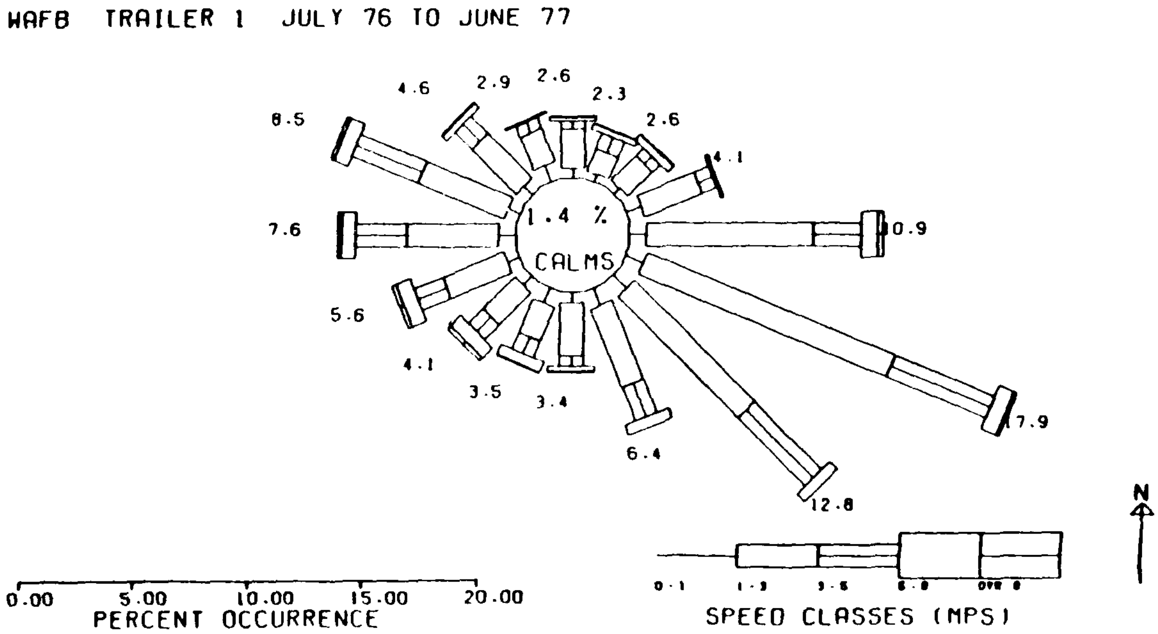

Figure 14. Annual wind rose at station 1, WAFB, from June 1976 to June 1977.

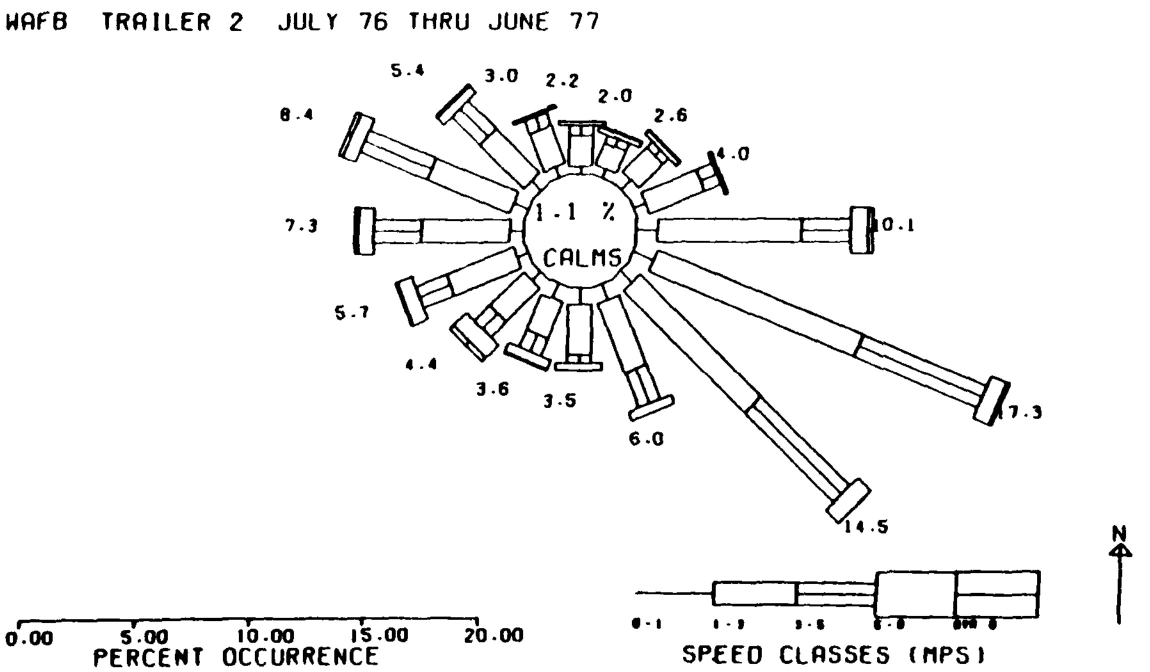

Figure 15. Annual wind rose at station 2, WAFB, from June 1976 to June 1977.

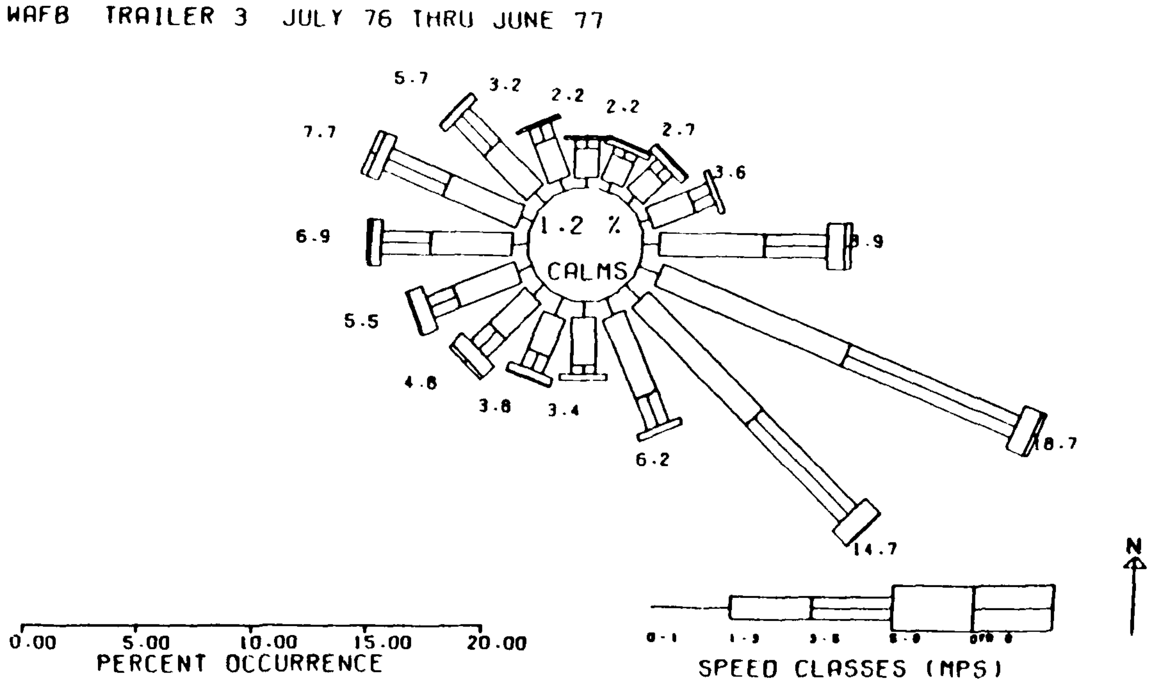

Figure 16. Annual wind rose at station 3, WAFB, from June 1976 to June 1977.

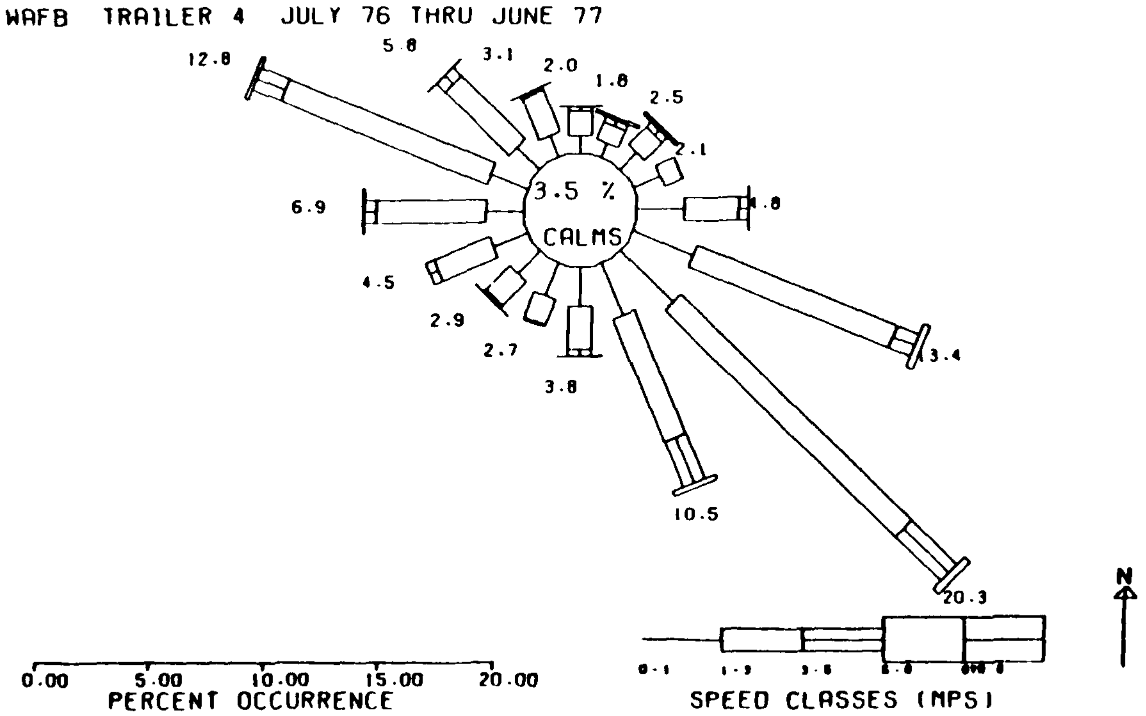

Figure 17. Annual wind rose at station 4, WAFB, from June 1976 to June 1977.

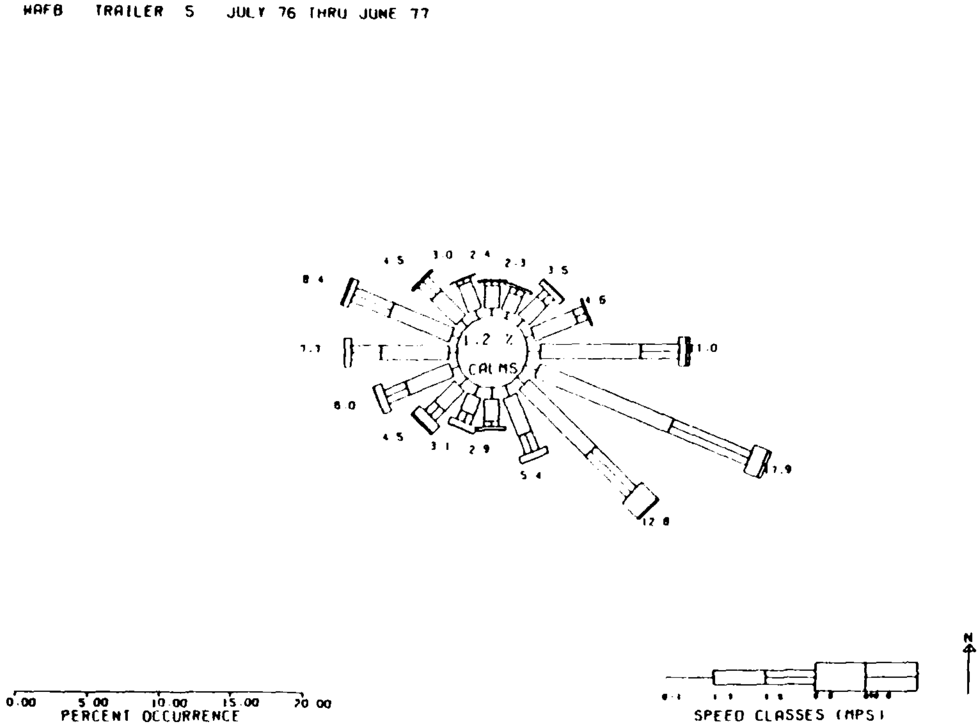

Figure 18. Annual wind rose at station 5, WAFB, from June 1976 to June 1977.

These frequency distributions of wind vector quantities provide information on the influence of wind on WAFB air quality. Visual inspection of hourly WS and WD averages plotted by the month (see Appendix h) shows a high repeatability among wind directions and speeds for stations 1, 2, 3 and 5. Visual inspection of the wind rose for each monitoring station shows a high degree of reproducibility between stations. More detailed analysis by Argonne National Laboratories has shown this to be true for monitoring stations 1, 2, 3 and 5 [14].

The direction and persistence of direction for wind at monitoring stations 1, 2, 3 and 5 (as seen in Figures 14 through 18) compare closely with the historical wind rose given in Figure 3. Station 4, located near Building 16 of WAFB and a complex of other base buildings (see Figure 4), exhibited a similar pattern to that of the other stations, although it did show a difference from the other stations in both WD and WS. WD is about 22.5° more from the southeast, and WS from station 4 shows a higher percentage of calms (WS less than 1 m/s). Station 4 WD and WS data appear to be influenced by nearby buildings in contrast to the other stations, which were located relatively free from obstructions to wind flow. The WAFB historical wind rose given in Figure 3 indicates a higher percentage of calm conditions. This may be attributed to the fact that the trailer wind speed sensors had a lower starting threshold than the WAFB anemometer.

Wind data in the tabular summaries were analyzed to define the relationship between WD and time of day. Examination of wind azimuth from these summaries (Figures H-1 to H-91, Appendix H) shows the east-southeast and west diurnal repeatability. During a high percentage of time, wind was light and from an easterly direction. By 1,000 hours, the wind began to veer to a westerly direction for the afternoon. By late afternoon wind was again light and variable in direction, with airflow typically veering clockwise to an east-southeast direction by evening. This wind direction persisted until sunrise. These observations are summarized in Table 10. About 50 percent of the time, the air motion was from lightly populated areas over a 95° sector to the east and southeast of WAFB. Winds came from the west or northwest only about 30 percent of the time.

TABLE 10. WIND DIRECTION AND TIME OF DAY

Duration (hours)	Wind Direction	Time
12	ESE	2000-0800
8	SE to W	0800-1300
5	W	1300-1800
2	Variable	1800-2000

4.5 OBSERVATIONS BASED ON ANNUAL AVERAGES

Cumulative Frequency Distributions

Hourly averages for CO, NMHC, NO_x, and nephelometer b_{scat} were pooled and divided into intervals of range for concentration and scattering coefficient according to an estimated increment of resolution of each instrument. Preliminary estimates of instrument measurement precision were used to select the concentration range classes presented in the log probability distributions. The cumulative frequency distributions for the 12-month period show a lognormal or near-lognormal distribution (Appendix K). The concentration ranges observed at WAFB were narrow in comparison to normal urban ranges.

The preceding discussion on instrument precision and bias can be applied to set limits on the usefulness of data shown in these frequency distributions. For example, single instrument precision estimates from all stations for CO imply that increments of detection are about 0.21 ppm on the average. Therefore, concentration changes less than 0.21 ppm at a single

station should not be considered significant. When using data from stations 1, 2, 3 and 5 for purposes of interstation comparison, the estimate of precision or instrument uncertainty os 0.3 ppm. Therefore a difference in concentrations of 0.3 ppm between stations is considered significant at the 95 percent confidence level.

Total relative variability between sites can be estimated by assuming lognormal distribution of the data shown in Appendix L for July 1976 through June 1977. The geometric mean and standard deviation were determined graphically from these figures, and these are shown in Table 11. The frequency distributions given in Appendix K also show characteristics useful in diagnostic judgment of data quality. For example, CO distributions show the greatest difference in shape between 150 and 200 pb -- probably the result of nonlinear detector behavior at each station for these concentration levels.

TABLE 11. 12-MONTH GEOMETRIC MEAN CONCENTRATION AND GEOMETRIC STANDARD DEVIATION FOR WAFB (July 1976 through June 1977)

Station	NO_x (ppb)		NMHC (ppb)		CO (ppb)		NEPH (10^{-4} m^{-1})	
	$\bar{x}$*	s**	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	8.0	4.3	60	40	100	43	0.5	0.24
2	8.8	4.1	130	84	120	46	0.5	0.25
3	9.3	4.3	88	62	80	40	0.5	0.21
4	14.0	8.0	175	97	250	160	0.5	0.24
5	8.5	4.5	78	44	13[illegible]	45	0.45	0.28

* $\bar{x}$ = 12-month geometric mean concentration
** s = Geometric mean standard deviation

Wind Direction and Air Quality at the Monitoring Stations

Diurnal persistence of wind for the two dominant directions and periods of calm conditions (winds less than 1 m/s) were used to sort hourly averages to observe major features of the data. Subgroups of hourly data were averaged for all monitoring stations and are presented in Tables 12 through 16.

The maximum and average pollutant concentrations -- as a function of calm, east-southeast and westerly wind directions -- can be used to identify wind conditions that produce highest concentration. Average concentrations for CO, NMHC, and NO_x are highest at all stations when winds are calm (less

TABLE 12. STATION 1 AVERAGE VALUES FOR JULY 1976 THROUGH JUNE 1977

	West Sector 236.25° to 56.25° Wind Points 12-3		East Sector 56.25° to 236.25° Wind Points 4-11		Calm Wind Speed < 1 m/s Direction Ignored	
	Maximum	Average	Maximum	Average	Maximum	Average
NO (ppm)	.0601	.0030	.0682	.0030	.0525	.0039
NO_x (ppm)	.0768	.0101	.0700	.0095	.0826	.0141
CH_4 (ppm)	3.1841	1.6000	3.3387	1.5962	2.3493	1.5796
THC (ppm)	3.2030	1.6642	3.8976	1.6392	2.2812	1.6549
CO (ppm)	2.0167	.1433	1.5903	.1248	1.2285	.1866
b_{scat}*	6.8138	.5050	4.4084	.5065	2.3297	.5879
WS (m/s)	12.4373	3.0943	12.8751	2.8979	.9989	.6414
NMHC (ppm)	1.1521	.0822	.9901	.0765	.6501	.0971

* $10^{-4}m^{-1}$

TABLE 13. STATION 2 AVERAGE VALUES FOR JULY 1976 THROUGH JUNE 1977

	West Sector 236.25° to 56.25° Wind Points 12-3		East Sector 56.25° to 236.25° Wind Points 4-11		Calm Wind Speed < 1 m/s Direction Ignored	
	Maximum	Average	Maximum	Average	Maximum	Average
NO (ppm)	.1603	.0035	.0654	.0031	.0302	.0037
NO_x (ppm)	.2915	.0122	.0935	.0110	.1067	.0162
CH_4 (ppm)	3.0897	1.6073	3.1203	1.6245	2.4224	1.6462
THC (ppm)	4.3471	1.6892	4.3279	1.6923	2.5358	1.7536
CO (ppm)	3.8692	.1726	1.5876	.1551	1.4208	.2286
b_{scat}*	7.4879	.5954	5.5254	.5790	3.3606	.6784
WS (m/s)	14.3444	3.1525	13.8851	3.0115	.9991	.6650
NMHC (ppm)	1.3517	.1407	1.3300	.1297	.7980	.1641

* $10^{-4}m^{-1}$

TABLE 14. STATION 3 AVERAGE VALUES FOR JULY 1976 THROUGH JUNE 1977

	West Sector 236.25° to 56.25° Wind Points 12-3		East Sector 56.25° to 236.25° Wind Points 4-11		Calm Wind Speed < 1 m/s Direction Ignored	
	Maximum	Average	Maximum	Average	Maximum	Average
NO (ppm)	.1332	.0028	.0333	.0027	.0371	.0038
NO_x (ppm)	.2412	.0134	.1137	.0120	.1106	.0171
CH_4 (ppm)	2.8521	1.5739	3.7748	1.5930	2.2259	1.6067
THC (ppm)	5.1778	1.6628	4.3843	1.6714	2.7936	1.7181
CO (ppm)	3.6703	.1315	1.7990	.1116	1.2230	.1530
b_{scat}*	5.3051	.5765	6.0275	.6167	3.2374	.6563
WS (m/s)	13.9436	3.1515	13.2470	3.0998	.9970	.6636
NMHC (ppm)	3.5704	.1077	2.0024	.1013	1.0099	.1280

* $10^{-4}m^{-1}$

TABLE 15. STATION 4 AVERAGE VALUES FOR JULY 1976 THROUGH JUNE 1977

	West Sector 236.25° to 56.25° Wind Points 12-3		East Sector 56.25° to 236.25° Wind Points 4-11		Calm Wind Speed < 1 m/s Direction Ignored	
	Maximum	Average	Maximum	Average	Maximum	Average
NO (ppm)	.1808	.0044	.0581	.0058	.0969	.0085
NO_x (ppm)	.3267	.0172	.1408	.0163	.1678	.0291
CH_4 (ppm)	3.0752	1.6480	3.8024	1.6286	4.2962	1.7728
THC (ppm)	4.6890	1.8023	5.3550	1.8230	7.1507	2.0910
CO (ppm)	2.7834	.2716	3.2887	.3403	3.9774	.5225
b_{scat}*	4.1974	.5250	5.7665	.5632	3.4194	.6677
WS (m/s)	9.3185	2.2021	8.3377	2.1904	.9997	.6395
NMHC (ppm)	3.0747	.1725	3.4413	.2061	4.9516	.3230

* $10^{-4}m^{-1}$

TABLE 16. STATION 5 AVERAGE VALUES FOR JULY 1976 THROUGH JUNE 1977

	West Sector 236.25° to 56.25° Wind Points 12-3		East Sector 56.25° to 236.25° Wind Points 4-11		Calm Wind Speed < 1 m/s Direction Ignored	
	Maximum	Average	Maximum	Average	Maximum	Average
NO (ppm)	.0594	.0040	.0315	.0037	.0648	.0049
NO_x (ppm)	.1111	.0131	.0837	.0100	.1075	.0174
CH_4 (ppm)	3.5836	1.6589	3.4403	1.6465	2.7673	1.6954
THC (ppm)	3.7205	1.7223	4.0057	1.7072	6.3742	1.8207
CO (ppm)	2.0612	.1910	2.1784	.1795	2.1724	.3123
b_{scat}*	4.3448	.5950	4.7254	.5466	4.0209	.6869
WS (m/s)	13.9948	2.9139	14.4455	3.0630	.9990	.6448
NMHC (ppm)	1.7339	.0969	1.2332	.0923	3.6069	.1484

* $10^{-4}m^{-1}$

than 1 m/s). As noted in the wind roses (Figures 14 through 18), however, calm periods occur less than 3.5 percent of the time for station 4 and less than 1.4 percent of the time for stations 1, 2, 3 and 5. Winds from the west occurred about 30 percent of the time, and averages of hourly data for CO, NMHC, and NO_x were higher for this condition, as opposed to easterly winds, for all stations except 4. Average CO and NMHC concentrations at station 4 are higher when winds are from the east-southeast (compared to the west sector), suggesting a persistent source of emissions or transport from that direction.

Maximum concentrations also generally occurred when winds were from the west. Exceptions were for station 1 in terms of NO_x and stations 4 and 5 in terms of hydrocarbons and CO.

A more detailed analysis is required to further identify specific source - receptor relationships. Cumulative frequency distributions, for example, show that concentrations of CO exceeding 1 ppm occurred at stations 4 and 5 for about 20 percent of the time. Concentrations exceeding 1 ppm for NMHC occurred about 5 percent of the time at station 4 and 1 percent of the time at station 5. Correlation of these data subsets to wind direction should provide additional insight to source impact.

On the average, CH_4 concentrations at station 1 on Williams AFB were 99 percent of the THC level. CH_4 comprised 96 percent of the THC when averages were selected for winds from the east-southeast. CH_4 usually contributes from 60 to 90 percent of THC concentration in urban atmospheres of North American latitudes and occurs in concentrations of about 1.25 to 1.5 ppm [14, 20, 21]. Station 4 CH_4 was 89 percent of the THC concentration, giving the characteristic of urban CH_4/THC ratio. In the development of atmospheric geochemical data, CH_4 has contributed as much as 95 percent of hydrocarbons present in desert (little vegetation) regions of the West (Summary Report, U.S. Department of Interior Oil Shale Leasing Program, C-B Shale Oil Project [22]). CH_4 and THC data at Williams AFB appear to be comparable and representative of Southwest air quality in general.

Comparison of WAFB Air Quality to National Standards

Carbon Monoxide--

Carbon monoxide concentrations (hourly averages) were examined in relation to the national standards. CO concentrations never exceeded the annual standard eight-hour average of 9 ppm or the one-hour average of 35 ppm. CO concentrations greater than 3 ppm occurred on 10 days for the July 1976 through June 1977 monitoring period. The day, time of day, and measured concentration are shown in Table 17.

TABLE 17. DATE AND TIME CO EXCEEDED 3 PPM

Station	Date/Hour	Concentration (ppm)
4	Oct. 19, 1976 0800	3.57
4	Nov. 18, 1976 0800	3.14
4	Nov. 29, 1976 0800	3.93
4	Dec. 3, 1976 0800	3.29
4	Dec. 7, 1976 0800	3.49
4	Dec. 21, 1976 0800	3.98
4	Dec. 29, 1976 1800	3.87
4	Dec. 29, 1976 1800	3.67
4	Jan. 10, 1977 0800	3.15
4	Feb. 3, 1977 1000	3.96

NMHC (Hydrocarbons Corrected for Methane)--

Nonmethane hydrocarbon concentrations were examined for the three-hour period from 6 to 9 a.m. in order to relate measured NMHC concentrations to EPA guidelines for hydrocarbons corrected for methane that serve as oxidant precursors. Three-hour averaged concentrations compiled from tabular summaries of NMHC exceeded the federal guideline of 240 pb 111 times during the 13-month period. On no occasion during the 6 to 9 a.m. period did NMHC exceed 1 ppm at any site. During the winter season of 1976, meteorological conditions resulted in higher measured NMHC concentrations.

Nitrogen Oxides (NO_x)--

NO_x concentrations have not been related to existing NO_2 standards since no data processing was performed to estimate NO_2 levels as the difference between NO_x and NO measurements. As seen in Table 18, the annual average concentration for NO_x did not exceed the 0.05 ppm annual NO_2 standard at any monitoring site.

TABLE 18. ANNUAL AVERAGE CONCENTRATIONS FOR ALL STATIONS JULY 1976 THROUGH JUNE 1977

Station \ ppm	NO	NO_x	CH_4	THC	CO	NEPH*	NMHC
1	.0031	.0108	1.6069	1.6552	.1411	.5468	.0822
2	.0033	.0119	1.6210	1.6984	.1672	.6017	.1374
4	.0060	.0197	1.6687	1.8813	.3609	.5790	.2252
3	.0028	.0129	1.5882	1.6718	.1213	.6061	.1056
5	.0039	.0118	1.6555	1.7231	.1958	.5753	.0994

* units of ($10^{-4}m^{-1}$)

4.6 ASSESSMENT OF IMPACT ON AIR QUALITY AT THE MONITORING SITES

The direction and persistence of direction for the wind at monitoring stations 1, 2, 3 and 5 was used as a basis for describing base air quality. The high percentage of time that this diurnal pattern is true for WAFB also suggests that a development of average background air quality would be representative for the area around the base.

Annual averages taken from tabular summaries for all stations are shown in Table 18 for the period July 1976 through June 1977. Station 4 stands out as

the location where assessment of air quality impact may be performed in terms of concentrations as a result of WAFB activity as opposed to local background conditions.

The diurnal persistence of wind direction was used as a basis to observe major features of the annual averages of data shown in the cumulative frequency distributions. Concentrations of NO_x, NMHC, and CO (when plotted for one day) were used to observe sources of emissions that may be located in areas surrounding WAFB. Nontypical meteorological conditions were usually associated with higher concentrations of NO_x, NMHC, and CO. Examples of episodes and higher-than-normal concentrations are shown in Appendix H, Figures H-92 through H-134. Specific examples are also shown for September 26 and December 29, 1976, and for January 27 and May 11, 1977.

Airbase air quality in contrast to background concentrations was developed through the rationale that average conditions and wind directions from all points of the compass should be considered for the description to be representative. Station 1 averages from east-southeast conditions are designated as background air quality. Comparison was done by averaging the annual average concentration for stations 1 and 5 to characterize base air quality. These averages contain contributions from airbase operations; however, they are the least impacted by base operations because of WD under typical east-southeast wind conditions. The approach was further justified on the basis that they are located at some distance from station 4, which may be considered as the location where the impact of all activity (including flight operations) may be highest during typical wind conditions. Slight impact on concentrations at stations 1 and 5 was detected for short periods of time (see Appendix H, Figures H-92 to H-101). Station 1 averages were summarized between the hours of 2000 in the evening and 0800 in the morning when wind was from the east-southeast. Background and base air quality concentrations developed from this approach are shown in Table 19.

TABLE 19. ANNUAL AVERAGE AIR QUALITY CONCENTRATIONS AT WAFB

Station	NO* (ppb)	NO_x (ppb)	CH_4 (ppm)	THC (ppm)	CO (ppm)	NEPH*	NMHC† (ppb)
			- Background-				
1†	3.1	10.8	1.61	1.66	140	0.52	62
			- Airbase (Including Background)				
1 & 5	3.4	11.3	1.64	1.69	169	0.57	91

* b_{scat} is in $10^{-4} m^{-1}$ units

† Concentrations from station 1 were averaged for the period July 1976 through June 1977 between 2000 and 0800 (see Table 18).

As can be seen from Table 19, the differences between the annual average concentrations selected to produce the lowest levels are insignificant in relation to the annual average for all periods of time at stations 1 and 5. Station 1 was least impacted by airport or aircraft-related activity. On an annual basis, the average of stations 1 and 5 is representative of the background, or base, air quality.

A comparison of station 1 and 5 average concentrations for NO_x, NMHC, and CO to those for station 4 is presented in Table 20.

TABLE 20. COMPARISON OF SELECTED ANNUAL AVERAGE CONCENTRATIONS

Station	Annual Average Concentrations (ppb)		
	NO_x	NMHC	CO
1 & 5	11.0	91.0	169
4	20.0	225.0	361
Difference	9	134	192

The difference in CO levels between station 4 and the average of station 1 and 5 was judged to be significant at the 95 percent confidence level. The differences for NO_x and NMHC were not significant at the 95 percent comfidence level.

During periods when the prevailing wind is from the east-southeast, station 1 average concentrations are not directly related to WAFB activities. This condition occurred for approximately 50 percent of the 13-month period. The percentage of time that measured air quality levels exceed those at station 1 is a good indication of the impact of airport or aircraft activity on base air quality as measured at station 4. Table 21 presents a comparison of annual average concentrations as measured at stations 1 and 4 during periods of east-southeast prevailing wind conditions. Also presented is a

TABLE 21. COMPARISON OF DATA FROM STATIONS 1 AND 4 DURING EAST-SOUTHEAST WIND CONDITIONS

Station \ ppb	NO_x	NMHC	CO
1	11	83	141
4	20	225	361
Impact Indicator	9	142	220

quantitative indicator of the difference between the station averages for the purpose of determining observed air quality impact, if any.

From inspection of the data in Table 21, it is apparent that there is an impact on base air quality during periods of east-southeast wind movement. However, without specific extraction of selected station data for discrete time periods and correlation to airbase operations records, no assessment can be made on the impact of aircraft or airbase activities and no determination can be made of potential emissions sources that have impacted the existing base air quality at station 4. Such analyses are possible with the existing data base, but they will be expensive in terms of labor and computer manipulation of tabulated measurement data. The success of such analyses will depend directly upon the degree to which the data search objective is specified prior to the beginning of any analysis.

Using existing annual average concentration data for stations 1 and 4, the following observations can be made on generalized air quality impact:

- For 21 percent of the monitoring period, there was a significant difference in CO concentrations as measured by stations 1 and 4 at the 95 percent confidence level.
- For 12 percent of the monitoring period, there was a detectable difference in NMHC concentrations as measured by stations 1 and 4, but the difference is not significant.
- For 6 percent of the monitoring period, there was a difference in NO_x concentrations as measured by stations 1 and 4, but it is not significant.

Since there are no major emissions sources (other than vehicular) in the proximity of WAFB, it must be assumed that the impacts noted above are due to emissions from local vehicular traffic (airbase personnel) or from airbase or aircraft operational activities.

Impact of air quality at stations 1, 2, 3 and 5 on an average annual basis is slight, at less than the 95 percent confidence level. There was no impact of air quality at these stations at the 95 percent level of confidence using the pooled precision of measurement estimates provided in Section 4.2 above and the definition of background base air quality.

4.7 RESULTS OF RELATED SPECIAL STUDIES

Several short-term studies sponsored by the USAF were carried out at Williams AFB and at other locations to measure vertical and horizontal dispersion of aircraft emissions and to develop empirical data useful in modeling.

Each of the following studies is summarized briefly in this section:

- EPA recommendations on the evaluation of AQAM
- Preliminary air quality analysis (1975)
- Horizontal wind dispersion parameter investigation
- Particle morphology of aerosols collected at WAFB
- Remote optical sensing of emissions (ROSE) study
- Correlation spectrometer (COSPEC) study
- Gas-filtered correlation (GFC) spectrometer study
- Scanning laser doppler velocimeter system (SLDVS) investigation

EPA Recommendations on the Evaluation of AQAM

EPA recommended a data analysis procedure for the accuracy definition being completed by ANL. Meteorological and emission data are critical input for modeling air quality concentration gradients. Accuracy definition requires the grouping of data for valid comparison of measured concentrations to model predictions. Once the data base are collected, valid data grouping according to real meteorological conditions is necessary to make comparisons. Several categories were proposed prior to analysis of any WAFB data, including meteorological categories such as wind direction and speed and atmospheric stability. It was recommended that two or three categories of mixing height be chosen in order to evaluate AQAM performance.

A cumulative frequency distribution of calculation error compared to measured data should be constructed to examine model performance for specific cases and to provide information on the distribution of over- and under-prediction for a specific category. Tests of the model accuracy would then depend on the user's supporting data analysis in terms of specific categories of testing. See Appendix B for further discussion of percent error distribution.

Preliminary Air Quality Analysis (1975)

The ambient air analysis study (mentioned in Section 2) was conducted as a preliminary guide to the development of the WAFB monitoring operations, and it provided qualitative information on plume rise and initial jet exhaust plume pollutant concentration as a function of downwind distance. The static jet portion of this study was conducted during idle and power engine modes while a helicopter made downwind passes at altitudes between 3.1 and 42.7 m AGL.

Relative concentrations (based on the averages from all traverses of the helicopter) were used to determine effective plume rise, which is useful for verifying vertical dispersion. From these averages it was determined that jet exhaust plumes were located at 7 m AGL, 50 m downwind; 20 m AGL, 100 m

downwind; 20 m AGL, 150 m downwind; and 21 m AGL, 200 m downwind. The full report is included in Appendix B.

Horizontal Wind Dispersion Parameter Investigation

The Pasquill stability class dispersion parameters are an important input to the approach used in AQAM. The purpose of the horizontal wind dispersion study was to determine how the subjective observation of stability class at WAFB (i.e., the method of determining stability class from WABAN observations [23] compared with the measured horizontal dispersion values from propeller vane wind measurements at each monitoring station.

A wind study was conducted at WAFB during the first week of monitoring, June 1976, using the R. M. Young Gill propeller vanes. These vanes are light and have fast time response. The average AGL height for the vanes was 8 m. Lightweight propeller vanes can effectively measure WS fluctuations in the 1 to 10 m wavelength range. WS fluctuation in this range is an important phenomenon in atmosphere diffusion.

From June 1 through 8, 1978, strip-chart recordings of WS and WD were collected for seven periods of several hours each from all monitoring stations of the network (see Figure 4). From these records, a shorter period of homogeneous turbulence (June 4 through 7) was selected for detailed analysis, when winds were generally light (below 5 m/s). Maximum temperatures were in the mid 30's (°C) and minimums were in the low 20's (°C), typical of summer weather in the Phoenix area.

The assumed similarity of turbulence readings between the trailers was tested by examining the strip-chart data using a five-minute averaging time. In a nighttime case, the values of horizontal dispersion (σ_y) were similar, except for station 4. In a daytime case, all values of disersion were sufficiently close to assume that similar turbulence took place at all trailers. Some of the station 4 charts showed greater variations in small-scale direction.

Calculations were performed to determine dispersion at different downwind distances. Different averaging times were used to calculate σ_y, and results indicate that, for averaging times of from 1-1/4 to 5 minutes, the dispersion parameters remain the same. Results were mixed, in some cases the σ_y values measured almost exactly parallel the Pasquill stability approximations. One early morning case indicated that a Pasquill Class A would be insufficient to describe the magnitude of instability at WAFB. For a daytime case, the magnitude of instability occurring over the hot WAFB runways exceeded Class A approximation. Longer averaging times were used to calculate some diffusion coefficients for an early morning period, and these calculations suggest that a Pasquill Class C would be more appropriate than a Class F, as suggested in the non-empirical approach to classifying stability.

A comparison of the average total variation of direction within the averaging time gives an indication of the turbulence intensity at small wavelengths. In the early morning hours, for example, fluctuation was 15° to 30°, whereas during the day the values were usually more than twice that. The

nighttime fluctuations were usually more dense as a result of mechanical turbulence caused by horizontal flow, but the daytime small-scale fluctuations were larger as a result of thermal turbulence.

Particle Morphology of Aerosols Collected at WAFB

In conjunction with a particle study being conducted in Phoenix in November 1975, the EPA requested that aerosol samples be collected at WAFB. Microscopic examination of the collected aerosols by the Illinois Institute of Technology Research Institute (IITRI) was conducted to determine what differences, if any, existed between particle types collected at WAFB and those collected in the Phoenix metropolitan area [18].

Aerosol samples were collected on November 17, 18, 21, 23-24 (overnight), and 25, 1975, with four samplers located at three different sites at WAFB: near site 4 at Building 16, at a remote sensing unit near site 2, and at a transmitter antenna near site 1 which had samplers situated at 1.55 m and 4.5 m AGL. Sampling intervals were chosen to take advantage of known windflow patterns in the Phoenix valley area.

All samples collected at WAFB were analyzed by optical microscopy. Some samples were further examined by scanning electron microscopy. Selected nuclepore filters were also examined by SEM. General observations made during the examination of each sample are given in an IITRI Report [18].

The particle size distribution data indicate that, on a number basis, the mean particle diameter at each sampling site was less than 2 μm. In addition to categorization by size, the particles were also categorized into two basic types -- mineral and nonmineral. The mineral category contained various soil minerals, fly-ash spheres, and higher density particles such as metal fragments. The nonmineral category included the fine carbonaceous particles, carbonized flakes, biological particles, and tire rubber particulate. Size distribution data obtained are presented in Tables 22 and 23 of Appendix B.

Remote Optical Sensing of Emissions Study

Long-path infrared spectroscopic measurements of CO concentrations were made by the EPA during the period February 10 through 19, 1976, at WAFB to provide integrated CO concentrations over the path length between two points. Remote optical sensing of emissions (ROSE) was included as a part of the USAF investigative program to attempt to overcome the inherent difficulty of comparing the average value predictions of dispersion models with the fixed-point values obtained from the five sampling stations. The sites (optical paths) for the ROSE measurements were chosen to be adjacent to major WAFB aircraft operations. The infrared light source and receiver units were equiped with telescopic optics to permit long-path (up to 3 km) measurements. The measured gas concentrations obtained in this manner are the concentrations that would be obtained if the gas molecules were uniformly distributed over the entire optical path length.

A total of 236 individual CO concentration measurements were made during the seven days of long-path data collection. Highest average CO

concentrations of about 4 ppm were measured along an optical path that traversed an individual jet plume for an appreciable period of time. Along other optical paths, most concentrations remained under 1 ppm. A path-averaged concentration of 3 ppm was measured about 20 m north of five idling jets at the east end of taxiway 5. Further information on this study may be found in Appendix B.

Correlation Spectrometer Study

Environmental Measurements, Inc. (EMI), under contract to EPA, performed six days of measurements from October 20-27, 1976, using the COSPEC correlation spectrometer. The goal was to document nitrogen dioxide (NO_2) pollution flux entering and leaving the base area. Additional data were gathered on regional pollution levels in the greater Phoenix area and in the vicinity of the Phoenix (Sky Harbor) Airport. Total sulfur measurements were also used as indicators of external emissions transport entering the WAFB area.

Sulfur dioxide (SO_2) and NO_2 overhead burdens were measured with the COSPEC remote sensor from a moving van. Total sulfur (TS) and NO_x were measured at ground level with continuous analyzers. The remote sensing COSPEC was also mounted on a tripod near the taxiway (site 3) for stationary measurements of vertical and horizontal profiles of NO_2. Another task was to monitor while circumnavigating the base on the perimeter road that circled the main aircraft operations area. The basic perimeter traverse was 13.5 km long and required 25 minutes to complete. These measurements around the base were carried out 25 times in six days. Typical observations for both total burden and ground-level measurements were that SO_2 values varied over 40 ppmM while the NO_2 varied over a 20 ppmM band of values.

Preliminary results were reported as follows [24]:

- Ground-level total sulfur at low concentration shows transport of this type entering WAFB to be limited.

- Ground-level NO_x variation is associated with vehicular traffic in the base area and along the perimeter of WAFB.

The stationary COSPEC results suggest a higher relative concentration of NO_2 to the northwest of WAFB toward the Phoenix area. A peak concentration has not been computed. The integrated level was 30 pmM at 2° elevation north-northwest of WAFB. A detailed report on the study is available in the EMI report, "Moving Laboratory Survey at Williams Air Force Base" [24]. Further summary information is presented in Appendix B.

Gas-Filtered Correlation Spectrometer Study

Three nondispersive infrared instruments were used at WAFB for long- and short-path remote sensing measurements [11].

The sensitivity of a GFC spectrometer depends on the correlation between the structure in the spectrum of the gas species to be measured and that of

the same species in the correlation cell internal to the instrument. This study is summarized in Appendix B.

Scanning Laser Doppler Velocimeter System Investigation

As part of the overall USAF program, data from a scanning laser Doppler velocimeter (SLDVS) were to determine the feasibility of using this system to map the concentration of particulate pollution in the atmosphere around airports. The system was operated at Kennedy International Airport from September 1974 through May 1975 for detecting and tracking aircraft wake vortices during landings on runway 31R. Since the system measures laser radiation back-scattered by particles in the atmosphere, it was postulated that the data from the system could be used to determine the concentration of these particles. The data consisted of tape recordings of digitized spectra along with time and spatial coordinates as a function of vertical and horizontal position. Approximately 450 such vertical signal profiles were prepared from data taken during 50 landings on five separate days in the spring of 1975. A complete report of this study, including vertical scans has been prepared by Raytheon Company [25].

A preliminary analysis of the data was performed to determine the relationship between signal and atmospheric backscatter coefficients and to evaluate the general quality of the resulting data. This data analysis indicated that the system was successful in measuring changes in returned signal strength, based on the repeatability of data from scan to scan.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The collection, processing, and analysis of all continuous air quality and meteorology data from the WAFB study have been completed. Hourly averaged monitoring data have been provided to ANL for use in AQAM accuracy definition analysis, and a preliminary assessment has been made of the observed air quality impact from WAFB aircraft and airbase operations. In addition, the results obtained from related special studies have been interpreted to provide relevant information concerning dispersion and transport of WAFB emissions.

This section summarizes the conclusions reached thus far (in relation to the major study objectives presented in Section 1) and presents recommendations for future airport air quality studies (specifically, those to be conducted at NAS Miramar in San Diego, California). Recommendations concern station siting, operational constraints, data collection, and analysis and interpretation of study results.

This report provides a qualitative assessment of the impact of aircraft emissions on air quality at Williams AFB. This assessment of the impact from aircraft emissions is defined for the purposes of this study to consist of observations of actual frequency distributions of concentrations of aircraft-related pollutants (CO, NO_x, reactive hydrocarbons, and particulates) at monitoring locations known to be subjected to aircraft emissions. Since the AQAM dispersion model yields predictions for one-hour average pollutant concentrations, and the second major objective of this study was to determine the accuracy limits of this model by comparison with observations, pollutant concentration measurements are reported as frequency distributions of one-hour averages. To estimate "impact" of emissions, frequency distributions in areas known to be subjected to emissions have been compared with frequency distributions observed in areas believed to represent "background" -- i.e., areas relatively unaffected by aircraft emissions.

The data are representative of all typical meteorological conditions around Williams AFB. Data were collected under conditions having the least potential for impact on air quality, which generally occur in the summer. Typically, as soon as the sun rises, any emissions from airport or aircraft operations disperse quickly in the desert climate. This observation is supported by the highly repetitive nature of this meteorological condition. Data were also collected during infrequent meteorological conditions that are conducive to high impact on air quality. In no case, however, did measured concentrations exceed or approach the national ambient air quality standards.

5.1 DATA BASE FOR AQAM ACCURACY DEFINITION

A data base consisting of 13 months of continuous air quality monitoring data has been successfully collected, edited, and converted to hourly average form for use in comparison to predicted ambient concentrations obtained from the AQAM formulation. Data recovery was 70 percent over the total period of monitoring, and the measurements obtained are representative of actual air quality levels encountered at ground level for the WAFB sites during the period from June 1976 through June 1977. Measurement accuracy limits have been determined for this data set based upon the measurement standard deviation of the data set and the calibration bias as obtained from daily check and station calibration records.

The ground air quality concentrations encountered at WAFB were often very low and in many cases approached the measurement sensitivity for the commercial analyzers used. As a result, the reported measurement accuracy limits are large in comparison with studies that involve higher pollutant levels associated with urban areas. Accuracy definition for AQAM, when used to predict air quality concentrations at WAFB, must account for these low physical measurement values, and predictions for CO, NO_x, and hydrocarbons must be representative of the low values obtained (on an annual average basis) at the five monitoring sites. Because of the low concentrations measured, AQAM accuracy definition will be very sensitive to the emission input data supplied prior to exercising the model. If any positive or negative bias in predictions is neglected, the data base collected should compare favorably to model predictions in the vicinity of the ground sites.

The low concentration values observed from the data base collected at WAFB indicate that the measurement of aircraft and airbase pollutants should not be conducted at ground level in locations immediately adjacent to the sources of emissions. In addition, the selection of actual measurement sensors should be based upon a preliminary study at the affected facility to determine background air quality and representative pollution levels at site locations where emissions are predicted to have measurable impact. Measurement sensor selection should also take into account the relative importance of NAAQS compliance data versus concentration data for use in evaluating the output of predictive dispersion models. The measurement sensitivity requirements for the latter objective are more stringent than those normally specified for the former, particularly in cases where observed air quality levels approach background concentrations.

5.2 ASSESSMENT OF AIR QUALITY IMPACT AT WAFB

Within the limits of measurement accuracy (as estimated in Section 4), the data reported indicate that, for the specific geographical area and associated meteorological patterns encountered, WAFB aircraft and airbase emissions did not have a significant impact on local base air quality levels. Measurements made during several related special studies indicate a high potential existed for transport and diffusion of aircraft emissions away from the airbase as a result of the buoyant plume rise normally associated with emissions that take place at elevated temperatures (such as in jet exhaust).

[illegible] were made at ground level [illegible] representative [illegible] conditions. Cumulative frequency distributions of hourly average concentrations for CO, NO_x, O_3, and NMHC were evaluated. These data are representative of WAFB air quality on an annual basis at ground level. The volume available for pollutant dispersion (mixing volumes), atmospheric stability, and other meteorological factors tend to reduce the potential for high pollutant concentrations at ground level in the vicinity of WAFB emissions.

At no time did measured air quality levels at WAFB exceed national standards. In many cases, measured pollutant concentrations approached background air quality levels for the WAFB geographical area. As a result, the determination of air quality impact from WAFB emissions was very difficult and relied heavily upon comparisons between pollutant concentrations at different stations. However, between-station variations must be carefully considered in light of the low pollutant levels measured, the resulting large percentage limits for measurement accuracy, and the local airbase meteorological and terrain factors that may have influenced individual station measurements at ground level.

The same data base that was collected for accuracy definitions of AQAM was reviewed to assess the impact of emissions on air quality at Williams AFB. Sorting the data as a function of wind direction and speed has not shown any major feature that indicates that WAFB emissions had a measurable impact on base air quality. Wind roses from the five monitoring sites show two dominant wind directions that are highly repeatable from day to day. Stagnant [illegible] represented about 2 percent of the time for the monitoring period. [illegible], located where base vehicular emission sources were evident, is [illegible] of airport-related activity. Airflow in and around this [illegible] affected by the proximity and height of nearby buildings. [illegible] site was lower, as evidenced by a higher percentage of calm [illegible], and parcels of air containing airbase emissions may have [illegible]. [illegible] pollutant concentrations were recorded at this [illegible] the highest percentage of time. Typical meteorological [illegible] were characterized by higher morning concentrations for [illegible]. Higher concentrations were evident in the afternoon [illegible] departed working areas, although this effect was less [illegible].

[illegible] from the east-southeast, station 4 air quality was [illegible] emission source downwind from sites 1 and 3. [illegible] and NMHC were higher from this direction than from the western [illegible], on an annual basis. Under stagnant wind conditions (high pollution potential), station 4 hourly averages of CO never exceeded 5 ppm and, on the average, were less than half the level of the national standard for CO.

The discernible features of the WAFB data set reported here are not sufficient by themselves to allow a vigorous determination of the air quality impact from WAFB emissions. Rigorous statistical tests must be applied to the data base to determine the significance of between-station variations in view of the low recorded measurement values. Without these tests, it is not

possible to state conclusively that an observed measurement variation is solely the result of the presence of an emission source. Similarly, it is not possible to identify or characterize any specific emission source without tests, such as multiple regression analysis, that incorporate all known independent sources of influence on air quality (including emissions, local meteorology, instrumental precision and accuracy, and terrain features). Faced with this situation, the use of a properly validated mathematical model becomes more desirable and practical.

5.3 RELATED SPECIAL STUDIES

To supplement the continuous air quality data collected from the network of five ground stations, a series of related special studies was conducted at WAFB. These studies included the collection of air quality and meteorology information using specially developed research techniques and instrumentation. While the special study results (presented in detail in Section 4) did not conclusively demonstrate that WAFB emissions were being transported outside the region monitored by the ground stations, they did indicate that a potential existed for dispersion of hot exhaust emissions, and they demonstrated the feasibility of using several monitoring techniques that were still in the developmental stage. In addition, the special studies pointed out the need for additional air quality measurements (above ground level) on future airport studies, and they provided qualitative indicators for the suspected mechanisms of emission transport and dispersion.

Studies that showed particular promise for the measurement of indirect sources in general, and line sources (highways, runways, etc.) in particular, involved long-path absorption principles. These methods of sampling air quality provided integrated measurements between two points, one of which was the energy source and the other the point at which absorption spectra were recorded. Problems encountered with these techniques include limited sensitivity and resolution in the concentration range of interest and lack of acceptable methods of calibration that can be related to other data.

Micrometeorology is perhaps the most important empirical data input to a model in terms of defining the representative accuracy of predictions. Boundary-layer profile research, together with advanced techniques of characterizing vertical dispersion, show promise in collecting airport emissions dispersion data. The helicopter platform provides a feasible way to develop quantitative emissions dispersion data at airports. The correlation spectrometer, as an upward-looking technique together with helicopter measurements of downwind dispersion data at airports. The correlation spectrometer, as an upward-looking technique together with helicopter measurements of downwind dispersion, shows promise of providing data to characterize the emissions flux and transport from aircraft sources.

Insufficient data were collected to relate mass-loading of particles to the measured nephelometer parameter b_{scat}. Further analysis is required to provide mass-per-unit-volume data at Williams AFB on a representative basis as related to continuous b_{scat} measurements. Data do suggest that the majority of particle sizes lie outside the size range where scattering is measured by

the nephelometer. Promising techniques are now available for particle monitoring in the vicinity of emissions. These are membrane filter sampling from ground and airborne systems as coordinated with forecasted meteorological conditions. Analysis may then be conducted to obtain a "fingerprint" of emissions, which is directly related to the source contributions.

Further review of the results of these special studies is recommended in order to optimize their potential for airport monitoring at other locations. Specific conclusions that have been made as a result of current analyses are presented in the same study order as that in Section 4.

Preliminary Air Quality Analysis

Three experiments were conducted in the preliminary study, and the distribution and transport of pollutants was inferred by:

- A study of pollutant concentration around the airport using grab samples conducted by ANL
- A study to estimate the effects of a single jet sitting in one place by measuring plume rise with helicopter measurements above ground, including grab sampling by ANL
- The ground-level measurements of concentration range with continuous air quality monitors

The effect of wind direction on concentration was examined by constructing pollution roses. This preliminary study appeared to confirm the feasibility of monitoring to develop one-hour average frequency distributions of air quality parameters at selected sites in the vicinity of emissions sources at Williams AFB. It was also felt that the emissions could be more accurately assessed by comparing air quality frequency distributions in areas with minimal aircraft emissions to those where aircraft emissions would be highest.

Horizontal Dispersion Study

Horizontal dispersion and fluctuation of wind direction can be used for comparison with Pasquill stability model parameters. In conclusion, because of the intense insolation in the Phoenix valley, the lower atmosphere varies from slightly unstable to extremely unstable throughout the day and into the night during summer. Pasquill stability classes seem to be low by an average of two classes. The most unstable case, Class A, is off by a factor of 2 or 3. The nighttime fluctuations were usually more dense because of mechanical turbulence, but the daytime small-scale fluctuations were larger as a result of turbulence.

Particle Morphology at Williams AFB

The major components of atmospheric aerosols in terms of mass at WAFB are minerals indigenous to the soil of the area. Motor vehicle traffic was partially responsible for resuspension of the soil minerals. Analyses in the size ranges collected indicated that the vehicles themselves contributed only

minor concentrations of particulates to the atmosphere. No relationship was established as characteristic of jet emissions.

Remote Optical Sensing of Emissions

Long-path measurements of CO showed 4 ppm average concentrations along a 670-m path through the plumes of five idling T-38 aircraft between the taxiway and inside runway. Visual observation of the jet exhausts and the fact that the highest CO concentrations occurred along this Path A, in contrast to a path adjacent to the runway, suggested that the jet plumes were rising.

Correlation Spectrometer Study

Results with the most potential for monitoring airport emissions in terms of NO_x were suggested through mobile perimeter measurements and stationary outward-looking measurements to locate varying concentrations. Peak concentration of these measurements was not computed; however, the data suggested that an NO_x source exists in the north-northwest direction toward Phoenix.

In contrast to the ROSE principle of measurement, which has its own energy source, the COSPEC uses the sun and can obtain a continuous record of oxides of nitrogen while moving to obtain a map of relative concentration with location.

Gas-Filtered Correlation Spectrometer Study

These devices were both fixed-point and long-path monitors. The principle of measurement is nondispersive infrared absorption, similar to that of the Federal Reference Method for CO.

The study did not provide data useful for plume rise description. Because the peak concentration and duration of concentration from jet exhaust is dependent on WS and WD, the length of time for observations of the plume was too short for the instrumental configuration used perpendicular to the runway. Response of the method is slow, and transient concentrations of CO were not present at instrument height for sufficient periods of time.

Scanning Laser Doppler Velocimeter System Investigation

The scanning laser Doppler velocimeter system (SLDVS) was used to map particles in wake vortices of aircraft at Kennedy International Airport, ancillary to the WAFB studies. Based on the repeatability of data from individual measurements, changes in returned signal strength were detected.

In summary, the principle of using an SLDVS for airport pollution monitoring of atmospheric backscatter coefficient appears to be feasible. A reasonable amount of data was obtained and processed with the system at Kennedy International Airport.

Summary of Conclusions for Special Studies

Pollutant concentrations measured by the helicopter showed the jet plume well above the normal height for measuring air quality from ground-level monitoring stations -- for example, the jet plume during one test appeared to be 45 meters AGL at 200 m downwind.

Vertical dispersion was investigated by the static jet study discussed in Section 2, an SLDVS study, and a Barringer correlation spectrometer (COSPEC) study. The acoustic sounder study (see Sections 2 and 4 and Appendix F) provided additional information for vertical dispersion, which was also investigated through a wind dispersion study, the COSPEC study, and a gas-filtered correlation (GFC) spectroeter study.

Remote or long-path air quality measurements can be used to measure buoyant plume rise of aircraft emissions and to estimate total pollutant flux arising from other sources on the airbase. Remote sensing instrumentation is also useful in measuring the average pollutant concentration over a given path for comparison with model calculations.

5.4 RECOMMENDATIONS FOR NAS MIRAMAR STUDIES

Based on experience gained at Williams AFB, four areas of data acquisition are recommended to monitor emissions and provide data for model evaluation at NAS Miramar in San Diego, California.

Statistical meteorological studies to develop conclusions about site locations, numbers of sites, and dominant sources should be implemented. Micrometeorological data should be acquired to determine horizontal and vertical dispersion parameters together with stability classifications. These can be obtained using tethered-balloon sampling platforms and dynamic air quality measurements using spectrometric principles.

It is recommended that measurement of air quality parameters be conducted for limited periods of time from fixed monitoring locations. Classification of meteorological conditions as statistically representative will then permit a choice of a monitoring interval consistent with the defined monitoring objectives, whether they be for model input data or impact assesent.

Emissions and their dispersion need not be monitored for extended periods, unless the data collected prove to be inconclusive. Data acquisition in the vicinity of emissions and in locations some distance from sources should be conducted to determine before-and-after changes in air quality. Planning of data analysis is recommended to determine what data are to be collected to meet end-use requirements.

Short-term intensive monitoring is recommended to determine the relationship of dispersion data to the fixed monitoring sites. Redundant monitoring technology should be applied concurrently to make efficient use of different forms of data. Airborne and ground-deployed sampling systems are

effective in this approach and can include sampling methods to determine the relationship of air quality measurements to source contributions.

Since the largest volume of data collected at NAS Miramar will be from ground stations in the vicinity of emissions, it is essential that rigorous statistical tests be applied to the data set to document air quality variation between monitoring stations. Information obtained at this stage can then be correlated with special study results to provide a complete assessment of the data for impact determination, documentation of standards compliance, and identification of emission source categories. Because of the San Diego locale involved, a primary objective will be the determination of background air quality prior to any airbase influence as a function of the predominant meteorological conditions.

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16. ABSTRACT

Air quality and meteorological data were collected continuously from a network of five ground monitoring stations located at Williams Air Force Base WAFB) near Phoenix, Arizona, during June 1976 through June 1977. Data reported here will serve as detailed input for defining the accuracy limits of the Air Quality Assessment Model. The data have been analyzed in order to determine the air quality impact attributable to WAFB operations.

Also reported are the preliminary results obtained from several related special studies designed to characterize horizonatl and vertical dispersion of WAFB emisions. The data indicate no significant air quality impact at WAFB resulting from aircraft operations.

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